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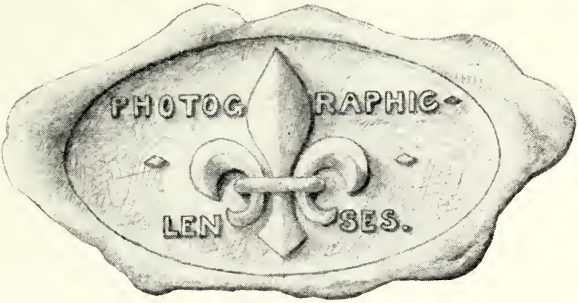
PHOTOGRAPHIC LENSES.

A SIMPLE TREATISE.



A SIMPLE TREATISE.

By CONRAD BECK and HERBERT ANDREWS.

2nd EDITION.
ONE SHILLING NETT.

LONDON:
R. & J. Beck, Ltd., 68, Cornhill, E.C.,
and
Percy Lund, Humphries & Co., Ltd.,
3, Amen Corner, E.C.

To Lens Users, these lines:—

Ah! make the most of what we yet may spend,
Before we too into the Dust descend;
Dust into Dust, and under Dust, to lie,
Sans Wine, sans Song, sans Singer, and sans End!

—*Fitzgerald.*

Competition. £15 in Money Prizes.

As we are anxious to perfect this book, in order that it may be as useful a manual as possible, we offer £15 (Fifteen Pounds), divided into the three following classes.

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£5 (Five Pounds) is offered for: The best list of corrections, either in grammar, style, or matter.

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    - (a) The name and address of competitor.
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8. All entries to reach us before October 31st, 1903.
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11. All negatives and prints submitted for competition are at competitor's risk, but every care will be taken of them while they are in our hands.

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Photographic Lenses. A Simple Treatise.

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All the blocks, whether line, half-tone or photogravure, have been produced with the aid of Beck-Steinheil and Steinheil Process Lenses.

* The Brief Summaries of each section are the Index to that section.

Inscription.

The following pages are not intended to give a full scientific explanation of the laws which underlie the construction of the Photographic Lens, they are published with the hope that they may be of use as a Practical Guide to the Practical Photographer, who, without wishing to deeply study Photographic Optics, is desirous of being able to use his apparatus to better advantage through a knowledge of the general principles which underlie its construction.

CONRAD BECK.
HERBERT ANDREWS.

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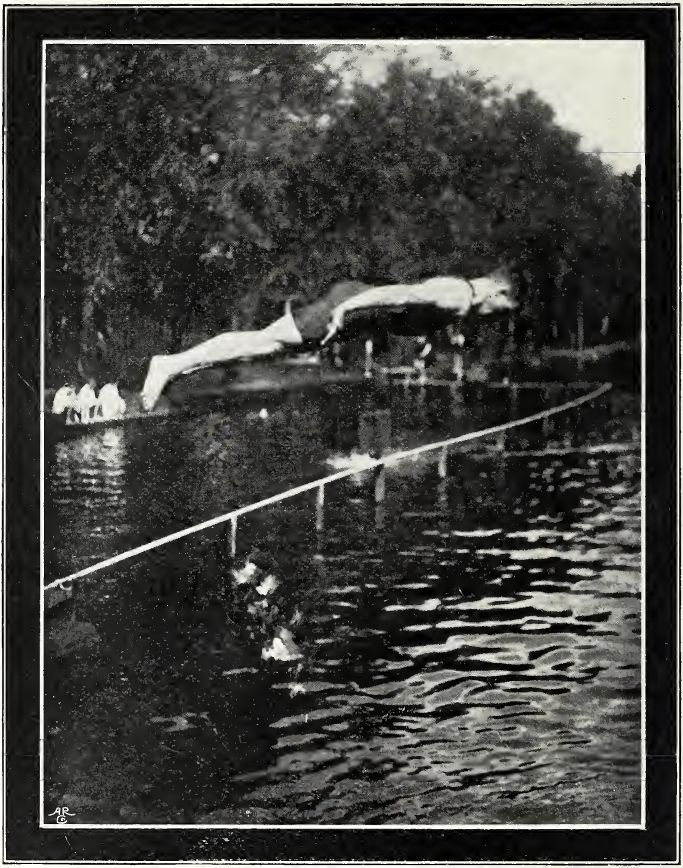
DIVING.



Negative by *M. Abrahams.*

Taken with a No. 3 Beck-Steinheil Orthostigmat at f/6·3 in a Penna Camera (Wallis patent).

PHOTOGRAPHIC LENSES

SECTION I.

PRINCIPLES AND FUNCTION OF A PHOTOGRAPHIC LENS.

The Photographer's outfit consists of several distinct items—Camera, Lens, Tripod, Plates, etc.—all of which have their importance, but it is upon the quality of the lens, combined with its proper use, that the value of the resulting photograph primarily depends. No excuse need therefore be offered for this attempt to guide the operator in making a proper selection and employment of this important piece of apparatus.

The definition of a photographic lens may be thus expressed:

"A piece or series of pieces of transparent media (glass) the surfaces of which are always portions of spheres."

Definition of a lens.

Its function is to project a picture of external objects upon a sensitive surface within the camera. It is therefore designed to collect as many rays as possible, emitted from a luminous point in the object which is being photographed, and to bring them to a corresponding point in the image plane (the photographic plate), so that every point in the object has its counterpart in the image.

To create by means of a lens a picture which shall be a faithful reproduction of its original is not simple. Some portions of the picture may be more accurately depicted, or better defined, than others. Distortion or other defects may be produced in varying degrees, and it is the object of the following pages to explain these defects and to discuss their relative importance in different lenses.

The pinhole.

The simplest of all methods of producing an actual image on the photographic plate is by means of a pinhole, and from a study of this, many of the qualities and capabilities of a photographic lens may be deduced.

To illustrate certain properties.

If a small hole be pierced in a thin piece of card or other suitable material, and this be placed in the position usually occupied by the photographic lens an image will be formed on the ground glass, of the object or view under consideration.

Upon investigating this image it will be seen that the pinhole has the following properties:

No Focus,
No Rapidity,
No Distortion,
Infinite Depth,
Infinite Angle of View,
Perfect Covering Power,
Perfect Equality of Illumination,
Very Poor Definition.

No focus.

When it is stated that a pinhole has no focus it is meant that at any position of the ground glass the image will be equally sharply defined. This is easily observed by moving the ground glass to or from the pinhole, when the picture will merely increase or decrease in size, and will not vary in sharpness of delineation (this is only true within certain limits, for when the screen is removed to a great distance considerable diffraction is introduced).

Rapidity.

Rapidity is dependent upon the amount of light that a lens is capable of receiving and conveying from a point of the object to its corresponding point in the picture. It is governed primarily by the size of the lens, which controls the effective aperture. In a pinhole so little light passes that the rapidity may be stated to be nil, indeed a pinhole is only able to produce an image on account of the fact that it approximates to a hole so small that one ray only can pass from each point on the object to its corresponding one in the picture.

Depth of Definition.

Depth of definition is the property possessed by a photographic lens, of producing a sharp picture of objects which are situated at different distances from it. It is possessed to a greater or lesser degree by all lenses, but a pinhole, having no focus, can reproduce with the same degree of sharpness, objects lying at any distance from it.

Angle of View.

Angle of view is the extent of the object or view included by the photographic lens upon the plate. In a pinhole, this is only governed by the size of the plate and the thinness or suitability of the material in which the hole is produced, and can be considered for the purposes of comparison to be unlimited.

Equality of Illumination.

Equality of illumination is the term used to describe the relative intensity of the light which a lens is capable of throwing to different portions of the picture. If a lens is so constructed that the edges of the plate are as well illuminated as the centre, the photograph when printed will not show any darkening towards the edges.

In the case of a pinhole the equality of illumination is perfect, provided the pinhole is made in suitable material.

Covering Power.

There are but few lenses which will produce a picture in which the marginal portions are quite as sharply defined as the centre. There will always be a certain area of sharp definition, and the size of this area describes the covering power of the lens.

In a pinhole the definition is the same over all parts of the field, it may therefore for purposes of comparison be considered as perfect. Definition, as a matter of fact, is very inferior in the case of a pinhole, that is to say, the image is not sharp anywhere. It is true that sharpness is a relative term, but a standard sufficient to satisfy the most modest requirements cannot be attained with a pinhole. The degree of sharpness is directly dependent on the size of the hole, but when the hole is less than a certain diameter a disturbing factor is introduced. Diffraction would be set up which would ruin the quality of the image by scattering light indiscriminately over the whole field.*

Sharpness obtainable with a pinhole.

Limitation of the pinhole.

From the foregoing cursory glance at the properties of a pinhole, it is evident that it would be an ideal "Lens" of infinite capabilities except for two properties.

It possesses no rapidity:

It is incapable of giving a sharp image.

The need for a lens.

These are, however, essential requisites for the production of a good photograph, and to overcome these defects the modern lens has been introduced. The whole aim and struggle of the "Manufacturing Optician" has been to produce a lens which does not suffer from these disabilities, but which shall combine to as large a degree as possible the advantages of the pinhole. The magnitude of the problem can be readily seen when it is remembered that some of the factors are interdependent, as for instance, increase of rapidity involves decrease of depth of definition.

IMAGE FORMATION.

Image formation by a lens.

Let A represent a point upon an object A B C. This point may be considered as being brilliantly illuminated and as radiating light in all directions.

---

*The fact that light may be considered to travel in straight lines is only true when a considerable bundle of rays is referred to. If a single ray were travelling by itself it would split up in all directions, this splitting up is called diffraction, and the nearer the bundle of light approaches to a single ray the more this irregular factor is introduced, and the more noticeable this error becomes in the resultant image.

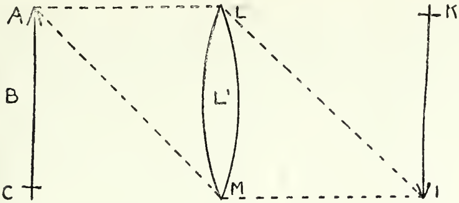


Figure 1.

Let the cone L A M represent all the light from the point A that can pass through the lens system L M. Now the point I cannot receive any light that passes through the lens system, except what is included in the cone L A M; no ray of light, for instance, that passes through the point C can reach the point I, because any such ray will be refracted by the lens system to the point K, thus the point I will be illuminated only by light radiated from the point on the object at A, and it will be a reproduction of that point. If A is bright it will be bright, if A is green it will be green. Thus every point in the object A B C will have a corresponding point in the plane I K, and an exact picture or image of the object A B C will be formed in I K.

Image formation by a pinhole.

This is equally true of the pinhole image, though in this case, the cone L A M can be considered as a single ray or a minute bundle of rays, the base being only the size of the pinhole. If a piece of ground glass or paper be placed in the plane I K the image of the object, if sufficiently brightly illuminated, will be visible to the eye. An image of this kind, which is actually existing in space, is called a real image. It is with this image that the photographic lens is concerned.

Real Image.

The image is invariably reversed or inverted, that is, the upper portions of the object are the lower portions of the image. A glance at

Inversion of the Image.

figure 1 will explain this point, an arrow has been taken as the object, and its image is reversed.

The following diagram indicates the difference between the image formation by a pinhole and by a photographic lens. In fig. 2, let O represent a pinhole supposed for argument's sake to be so small that only one ray of light is allowed to pass, forming an image at BB' of the object AA'. As light travels in straight lines it is evident that the image is formed because the point B' can only be illuminated by one ray of light, namely, that proceeding from A, B will be illuminated by the ray from A', etc. No ray of light from A could reach B to take part in the formation of its image.

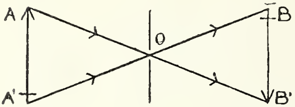


Figure 2.

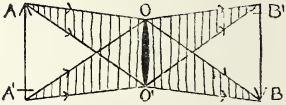


Figure 3.

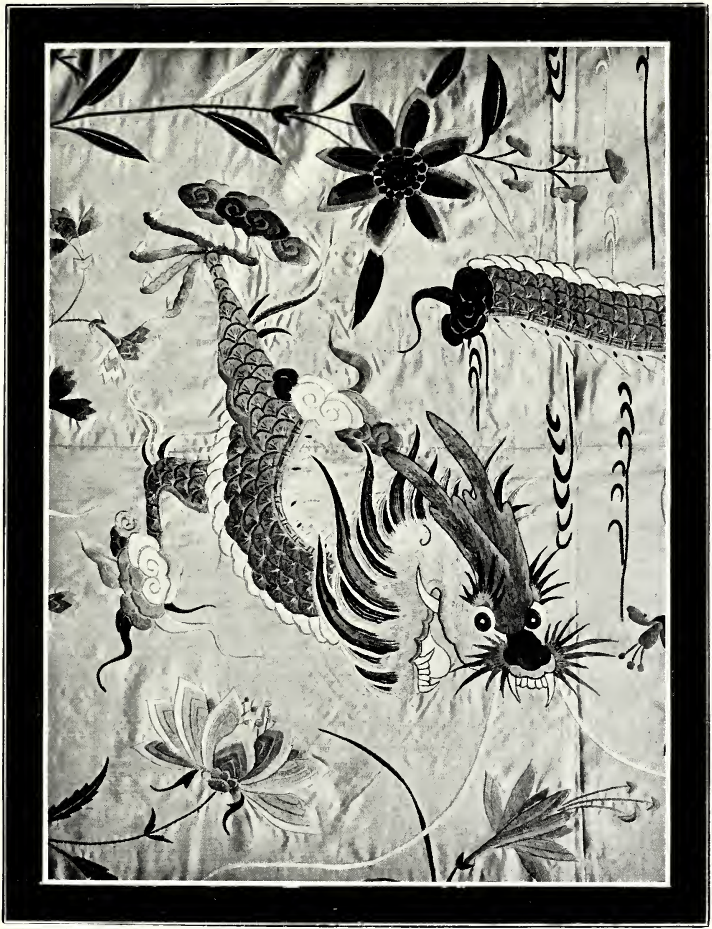
Difference in image formation between a pinhole and lens.

In figure 3 a ray travelling from A and impinging on the lens at O is bent during its passage through the lens and is directed to B. Another ray travelling from A in a different direction impinges on the lens at O', and is also bent, but in an opposite direction, and also arrives at B. In the same way all rays from A lying between O and O' are brought to a point at B. When it is remembered that the lens is circular, then all within a cone with A as the vertex and OO' as the diameter of its base, will be brought to a point or focus at B. Thus a large number of rays, instead of a single one are used in the formation of the image. The time required, therefore, to impress an image on a photographic plate will be reduced. In a similar manner all rays emitted from A' and travelling within a cone having OO' as its base will be converged to B',

See page 52.

PLATE I.

CHINESE SILK.



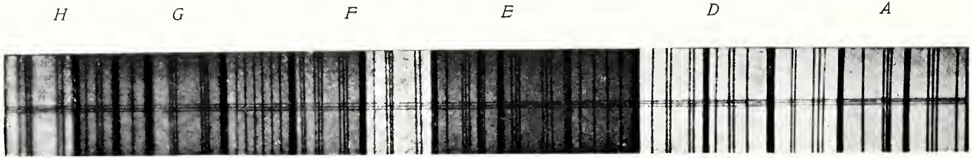
Negative by *F. O. Bynoe.*

Photograph of a piece of Multi-coloured Chinese Silk, showing perfect colour correction of a lens, reduced from a 12 × 10 plate.

Lens, Beck-Steinheil Orthostigmat No. 8, 11-inch focus.

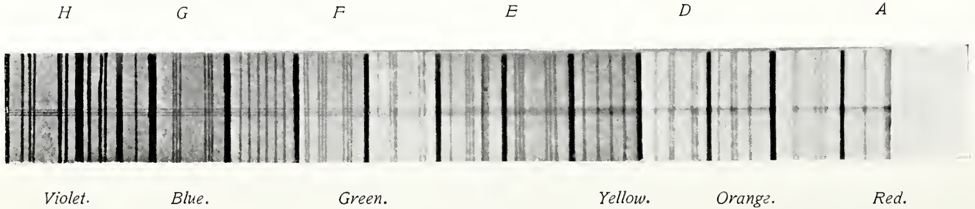
See page 55.

PLATE II.



Photograph taken of a spectrum-coloured diagram with a lens badly corrected for colour, focussed in ordinary light, showing that when this is done the yellow-coloured portion is sharp.

PLATE III.

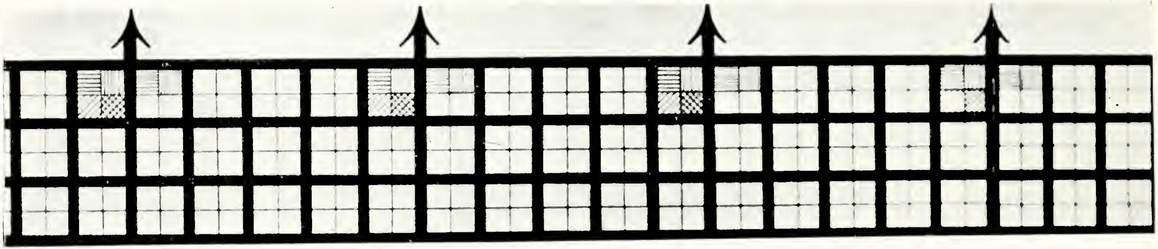


The same diagram photographed after correction, for "chemical focus," has been made, showing blue and violet-coloured portion sharp, and yellow and red indistinct.

See page 61.

PLATE IV.

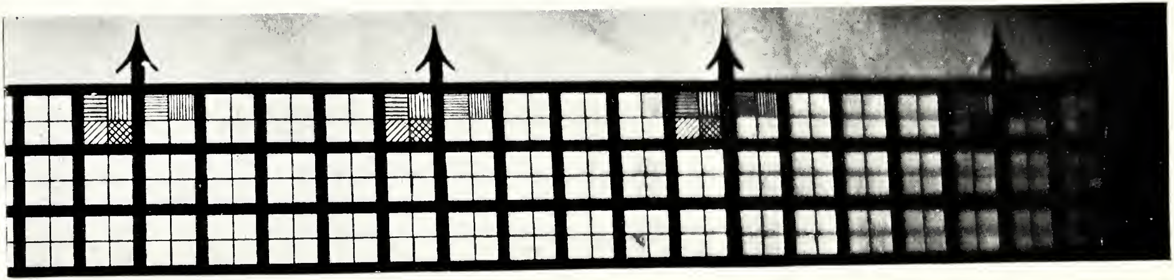
CENTRE OF FIELD (to enable the photograph to be shown on a larger scale, one half only is reproduced).



A photograph of a test chart with a 5½-inch (Frena Beck Lens) good Single View Lens, f/11.

PLATE V.

CENTRE OF FIELD (to enable the photograph to be shown on a larger scale, one half only is reproduced).



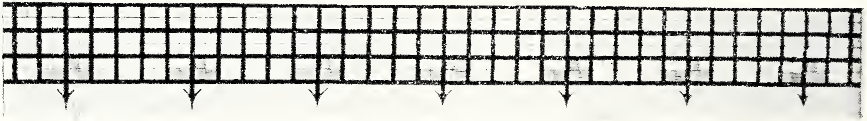
A photograph of the same chart with a poor 5½-inch Single View Lens, f/14.

See page 67.

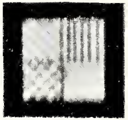
PLATE VI.

CENTRE OF FIELD (one half of the photograph only is shown).

A

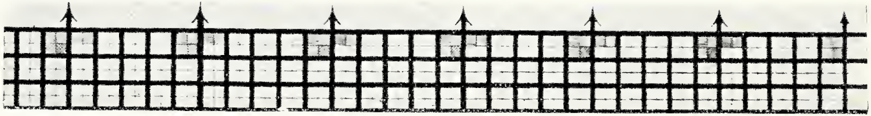


From a photograph of a test chart taken with an Anastigmat f/6·8.

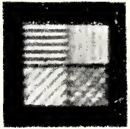


Magnified square from the edge oj the chart.

B.

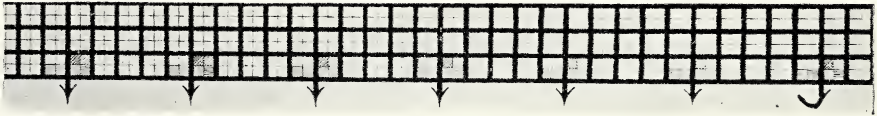


From a photograph of a test chart taken with a different Anastigmat, f/6·8.

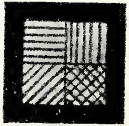


Magnified square from the edge of the chart.

C.



From a photograph of a test chart taken with a Beck-Steinheil Orthostigmat No. 4, f/6·3.



Magnified square from the edge of the chart.

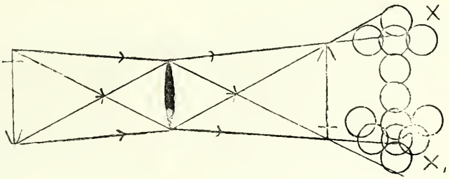
similarly with points in the object between A and A′.

Thus all rays emanating from the object AA′ which strike any portion of the lens are converged and brought to a point in the image. If the ground glass or plate be placed in this plane BB′ it will receive the picture upon it.

Position of the plate to produce a sharp image.

In order to produce a sharp photograph, it must be placed in or very near to the plane BB′, otherwise each point of the object will not be represented by a point in the image, but by a small circle, because this image is formed by a series of cones of rays (see figure 4, XX′).

Figure 4.



A lens, therefore, has a focus. A pinhole has no focus, for wherever the ground glass is placed the image formed by single rays will give an equally sharp picture.

The two unavoidable defects of a pinhole.

(1) Lack of Rapidity.
(2) Lack of Definition.

These are overcome by a photographic lens. To what extent they have been surmounted and what attendant evils accompany the advantages gained, it will be the part of the following pages to consider.

To obtain the first of these objects, increased rapidity, an increased volume of light must be collected by the lens, and to fulfil the second condition, perfect definition, all these rays must meet at exact points.

In the opening pages, it is laid down that a lens is "one of a series of media, usually glass, bounded by spherical surfaces."

It will be well to explain the general principles whereby a lens can bend or refract light. When a ray of light passes into a medium denser than air, such as glass, it is retarded, and the result following from this, is, that unless it passes into the medium in a direction exactly at right angles to its surface, it is bent, or, as it is called, refracted.

The principles of refraction.

The ray AB′, figure 5, is bent at the point O into a direction OO′, meeting the second surface at some point O′; here it is again bent upon emerging into the air, and, due to the fact that the two surfaces are parallel, it meets the second at the same angle at O′ as it left the first surface at O. It is clear, therefore, that it must be bent to exactly the same extent as was the case when it entered the glass, but in an opposite direction; consequently the emergent ray O′B is parallel to the incident ray AB′, and the light in passing through a parallel plate of glass has suffered no alteration in its direction, but has merely been displaced laterally. Suppose, however, that the two surfaces of glass had not been parallel (figure 6).

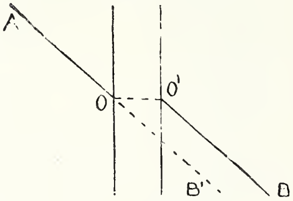


Figure 5

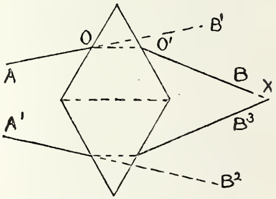


Figure 6.

The ray AB after its first refraction, does not now meet the second surface at the same angle at the point O′ as it left the first surface at the point O, and is therefore not bent upon emergence into the air at the second surface, in a manner to exactly compensate its original refraction. In fact, in the particular case shown in figure 6, the ray AB′ being at right angles to the second surface, is refracted still further from its original course AB′. Thus the ray AO, after having passed through both surfaces of the glass, is deviated from its original direction and emerges in the direction O′B. A prism, as illustrated in figure 6, deflects the light away from its apex. If another prism be placed (figure 6) with its base against the base of the first prism, the ray A′B² will be deflected in a similar manner, and may be considered to cut the ray O′B in X.

Rapidity.

If this be carried further, as in figure 7, and four portions of prisms be arranged as indicated, four rays can now be made to converge and meet in X. A spherical surface may be compared to an infinite number of prisms so arranged that their surfaces are absolutely blended, and in this case (figure 8) any number of rays striking the first refracting surface can be converged to a point X (the focus). It is upon the degree of accuracy with which the rays are brought to a point that the quality of the lens depends. It is upon the number of rays brought to this point that the rapidity of the lens depends. If it is ever possible to fulfil these conditions to their limit, an ideal lens will result.

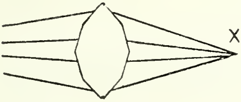


Figure 7.

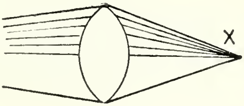


Figure 8.

How far this is possible and what means have been adopted to overcome the difficulties which are encountered, will be discussed later.

A simple lens is not free from error,

It is unfortunately not correct to assume that a pair of spherical surfaces forming a biconvex lens, as shown in figure 8, are perfect in their action, as such a lens gives only a rough approximation to the desired result, as will be explained later.

The ideal lens.

An ideal photographic lens would be one possessing the following properties:

(1) No Focus.
(2) Infinite Rapidity.
(3) ,, Depth.
(4) ,, Covering Power.
(5) No Distortion.
(6) Perfect Illumination.
(7) All Light striking the first surface to be utilized in forming the Image.
(8) A Perfectly Flat Field.
(9) Perfect Sharpness.

It is important to consider how far it is possible to satisfy all these conditions, though they will be more fully treated under section IV.

Focus.

No. 1 (Focus) can never be attained. A lens, because it is a lens must have a focus, but lenses can be made with any given focal length, and it is open to the photographer to choose what focus is most suitable for any particular work he may be engaged upon; this need not therefore be regarded as a serious drawback.

Rapidity.

No. 2 (Rapidity) can be attained in varying degrees. The degree necessary varies with the work required of the lens. This property can be regarded as having been satisfied by the opticians.

Depth.

No. 3 (Depth) is directly dependent on the rapidity. The greater the depth the less the rapidity, hence if this condition is fully satisfied the lens will have no rapidity.

Here a compromise has to be made and no method of manufacture can overcome this difficulty. The photographer is given a means of varying the two factors, by the iris diaphragm, whereby the rapidity can be increased or decreased, and thus the depth of definition be decreased or increased as circumstances may demand.

A compromise can usually be found to satisfy any set of conditions.

Covering power.

No. 4 (Covering Power) has already been referred to in connection with the pinhole. The best modern lenses (Orthostigmats) may be regarded for all practical purposes as perfect. In lenses that are not so perfect, the covering power can be improved by reducing the rapidity.

Distortion.

No. 5 (Distortion). The distortion here referred to must not be confounded with that caused by tilting the camera or by the faulty manipulation of the photographer. It refers solely to that distortion due to an imperfection of the lens which causes straight lines in the object to be rendered as curved lines in the image.

This distortion has been overcome by the manufacturers in all the better classes of instruments. Forms of the error, due to other causes are dealt with later, but they do not depend on the quality of the lens, but upon its incorrect use.

Illumination.

No. 6 (Illumination). Perfect illumination is the property which enables the lens to throw as large a quantity of light to the edge of the field as to the centre.

Strictly speaking perfect illumination is impossible in a lens system, but lenses have been recently much improved in this respect. A good lens catalogued to cover a given plate will do so and will give approximately equal illumination over the whole area.

Utilization of light.

No. 7 (Utilization of Light). The whole light that strikes the first surface of the lens must be used in the formation of the image. If, on account of imperfections in the lens or the presence of unsuitable reflecting surfaces, any light has entrance to the camera which does not help in the formation of the image, it will tend to produce a slight veil or milkiness over the picture, destroying its brilliancy. The shadows will not be so black nor the high-lights so white, as would otherwise be the case. The loss of light due to absorption by unsuitable glass or to throwing back by reflecting surfaces, is a less important matter, as although it may reduce the rapidity of the lens it does not impair the quality of the image. The best lenses may be considered to be adequately corrected in these respects.

Flatness of field.

No. 8 (Flatness of Field). By a perfectly flat field is meant that the picture formed by the lens is situated on a perfectly flat surface, which is free from curvature.

The degree to which this is fulfilled by the photographic lens varies, but in a lens such as the Beck-Steinheil it can be regarded as being perfectly flat. (See Astigmatism, Section III).

This will show that in the field of a lens of this type the variation from the flat is sufficiently little to be negligible over an area of 60°.

Definition.

No. 9 (Definition). Perfect sharpness in itself is unattainable, but in photographic work, if a point is represented by a circle of not more than 1-200 of an inch in diameter, it is considered to be sharp.

Such a degree of sharpness may be obtained with any but the commonest of lenses, and is frequently surpassed.

It will be gathered from the foregoing pages that every good lens should have the following properties:—

Properties of a good Lens.

(5) No Distortion.
(6) Even Illumination.
(7) The whole of the Light striking the First Surface utilized in the Image Formation.
(8) A Flat Field.
(9) Brilliant Definition.

But the most suitable focus, rapidity, depth

Properties that can be varied.

and covering power may be selected according to circumstances. The skill and energy of the optician has surmounted most of the difficulties which, in the early days of photography, stood in the way. And although perfection has not and probably will never be reached, vast strides have been made in recent years.

In a later chapter where the properties of different types of lenses are fully discussed, it is shown that the nature of the work to be done governs the choice of a lens; no lens can be found that will do everything equally well. Some are more suitable for one kind of work and some for another, for instance, a specially rapid lens made for photographing restless children will be of little service in reproducing an extended landscape, and particulars will be given which will enable the photographer to make a suitable choice by indicating the properties which are required in lenses to fit them for different purposes.

Brief Summary of the Chief Points in Section I.

(1) The definition of a "Lens."

> "A piece, or series of pieces, of transparent media (glass) the surfaces of which are always portions of spheres."

(2) The function of a lens.

> "To project a picture of external objects upon a sensitive surface within the camera."

(3) This image is inverted.

(4) A pinhole is unsuitable because—

- (a) It has no rapidity.
- (b) It is incapable of giving sharp definition.

(5) The aim of the optician is to produce a lens having the following properties. If this were possible an ideal lens would result. They are—

- (1) No focus.
- (2) Infinite rapidity.
- (3) ,, depth.
- (4) ,, covering power.
- (5) No distortion.
- (6) Perfect illumination.
- (7) All the light striking the first surface of the lens to be utilized in forming the image.
- (8) A perfectly flat field.
- (9) Perfect sharpness.

(6) Every good lens should have properties 5, 6, 7, 8 and 9. but the most suitable Focus, Rapidity, Depth and Covering Power may be selected.

SECTION II.

GLASS AND THE MANUFACTURE OF LENSES.

Glass.

Among the numerous works on lenses there are few, if any, which give an account from actual experience of the process of manufacture. Such an account may be helpful in differentiating the various forms of lenses between which an amateur or professional is called upon to choose. It may tend to dispel the idea that lenses of high price are yielding enormous profits to their manufacturers, and have not advantages corresponding to their price; it will show without undue emphasis the impossibility of a cheap lens fulfilling to the required degree the conditions suggested in Section 1. At the same time it may help the photographer to realize the difficulties of manufacture and to appreciate what defects are of importance and what may be ignored, when purchasing a photographic lens.

Liquid Lenses.

The vast majority of lenses now in use are composed of glass in some form or other, and it is not within the scope of this work to refer to occasional deviations. Sutton's spherical water lens has passed out of use, and Dr. Grün's adoption of the liquid principle has yet to establish its reputation.

Glass has probably been employed since the time of the Greeks for the manufacture of lenses, but it is only within the last century that it has been produced with the necessary qualities to enable any degree of perfection in lens construction to be reached. The introduction of photography greatly stimulated the optical glass industry, and as the more urgent necessity for perfect lenses has arisen, the glass industry has kept pace with the demand.

Properties of glass.

The properties necessary for making the corrections in lenses for photographic purposes are—

(1) Refracting Power (Refractive Index).
(2) Dispersive Power (in relation to colours).
(3) Stability under varying atmospheric conditions.
(4) Colour of the Glass.
(5) Physical Defects.

The first two are positive properties utilized by the optician to produce certain results. The last three are defects which must be avoided, they are not utilized in effecting the corrections.

Refracting power.

This property has been referred to in the first section when describing how a lens can bend or refract light. The refracting power of different kinds of glass is widely divergent, it is varied by the materials used in the manufacture. Lead, nickel, phosphorus and other metals often enter into the constitution of the glass, and its optical qualities depend upon the proportions of its various components. The measure of its bending power is called its refractive index.*

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* NOTE.—LAW OF REFRACTION.

When a ray of light travelling in a straight line passes from one medium (air) into a denser medium (glass) at any angle, not a right angle, it is bent in towards the perpendicular or (normal) to the surface at that point, and on passing out from the denser medium is bent still further in the opposite direction from the normal.

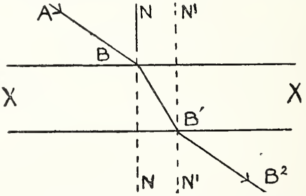


Figure 10.

In figure 10 let X represent a plate of glass and A B B² a ray of light striking its upper surface at B. The line N N being the normal at that

Dispersion.

The effect which gives rise to the sensation of white light in our eyes is supposed to be produced by the combination of a large series of rays of light all acting together on the retina of the eye. If such a composite ray, emerging from the sun or some other powerful light-giving source, be considered, it will be found to consist not of one ray with a single wave length, or period of vibration, but of a great number all travelling together and differing only in their wave length or period of vibration. On closer examination of this ray, it will be seen that it consists of an ascending series of vibrations, each having a slightly shorter wave length than the last, and all travelling together.

Coloured Light.

It is interesting now to see the way that the various vibrations affect our different senses. If those waves only that have very long wave lengths be isolated, no effect is produced on the eyes, but a thermometer placed in their path indicates that these have heating power. When a portion of vibrations with rather shorter wave lengths is considered, the effect of heat is still produced, but one's eyes are also affected, and the result obtained is what is called red light. Isolating yet again another portion, with still shorter vibrations, the effect they produce on the eye is again light but of a different colour—yellow. The next vibrations produce the colours to the eye of orange, blue, and violet, in the order of the spectrum, until at last a point is reached where no further effect of light is produced. The vibrations do

Different vibration different colours.

---

point (B) as the glass X is the denser medium, the ray A B will be bent in towards the normal as B B′, B′ being the point where it touches the lower surface of the glass X. On leaving the plate at B′, as it now passes into the less dense medium, air, it will be bent away from the normal N N′ at this point, as B′ B^2.

It is found experimentally that the sine of the angle (A B N) which the ray A B makes with the normal N N bears a strict fixed relation to the sine of the angle (N B′ B^2) which the ray B B′ makes with the normal N N. In other words the sine of the angle of incidence is to the sine of the angle of refraction in a constant ratio dependent on the nature of the glass. In ordinary crown glass this co-efficient is about 1·5, and is called the refractive index.

not, however, cease here. There are vibrations with still shorter wave lengths than those which cause light, and these, together with green, blue and violet, are the waves which affect the photographic salts of silver.

One must not suppose that there is any radical difference between these rays beyond the difference in their wave length. They affect different senses in different ways. The vibrations that are beyond the visible end of the spectrum would give rise to light, except that the eye is not sufficiently delicate to see them. There is every reason to believe that they are visible to some of the smaller animalculæ. The same applies to the heat rays, and if the eye were but sensitive enough, it is possible that there would be no need to ask a companion if he found the room too warm, as one could see if it were so.

Now, refraction is due to the fact that the wave length of light is altered by passing from one medium into another of different density. Light, however, does not consist of one vibration, but of a series, each with a different wave length, and it is a fact proved by experiment and accounted for by theory, that these different vibrations have their wave lengths altered in passing from a rare medium into a denser, in different degrees.

Chromatic Aberration.

It has been shown that it is possible to construct an optical system that will refract a bundle of rays to a single point, but in doing so it has been assumed that the light was caused by vibrations of the same length, namely, that it was the same colour. The rays, however, have not the same wave length. This defect, namely, that a bundle of white light entering a lens does not come to one point owing to the fact that light of different colours is refracted to different extents, is called chromatic aberration, and the correction of this error is most important. The amount of difference between the refraction of the extreme colours when passing through a glass is called the "dispersion" of that glass.

Dispersion.

The dispersive power of glass is its power of splitting up a ray of white light into its various primary colours. It varies in different kinds of glass according to their composition. This variation is not necessarily in the same ratio as the refracting power, two glasses may have the same refraction and different dispersion and vice-versa. The usual experiment to demonstrate this property is familiar to all.

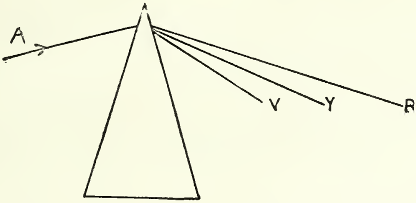


Figure 11.

Experiment to demonstrate dispersion.

If a prism (fig. 11) be placed in the path of a ray of white light A B, this ray will be split up into a number of component rays overlapping each other and varying from red through yellow to violet. The violet rays, as will be seen from figure 11 are bent the most and approach most nearly to the base of the prism; in an uncorrected lens they come to a focus nearer to the lens than the red. The amount of difference between the paths of the rays A R and A V is the measure of the dispersive power of the glass of which the prism is made. It is the green, blue, and ultra-violet rays that take the most active part in the formation of the image on the photographic plate, but the yellow rays are the most clearly visible to the eye. The necessity then of bringing these rays to the same focus as the violet will be evident.

Uncorrected lens.

In figure 12 the rays AA′ are split up by the uncorrected lens so that the blue or violet rays are brought to a focus at V, the yellow rays, however, do not come to a focus till Y and the red till R. Hence if the ground glass were placed where the most brilliant image to the eye was formed, namely, at Y, the picture would be out of focus, as the most chemically active rays, those which affect the plate, come to a focus at V.

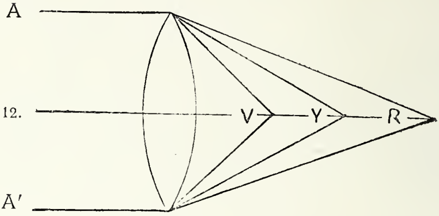


Figure 12.

Relation of refractive and dispersive power.

If the dispersive power of glass were always in exact relation to the refracting power, no correction for the chromatic error would be possible; that is to say, if low refraction meant low dispersion and high refraction meant equally high dispersion, a lens which, to have a focus, must refract or bend the rays, would always also have dispersive power to the same degree.

For many years this was thought to be the case by astronomers, who consequently turned their attention to the production of an image by reflection. But it is, as before mentioned, within the power of the glass maker to vary the relation of the refractive powers, and a glass with a low refractive power can have a high dispersion and vice versa.

Glass for lens making.

It is largely due to the great advance in glass making in recent years that the finest products of the lens manufacturer are possible. Nevertheless, some lenses of the highest quality are being made, composed of the glasses that have been available for many years, and recent mathematical work has shown that the methods of employing the older forms of glass are not yet exhausted.

Constituents of Glass.

The manufacture of glass dates back to an early period, and so long as it was used for everyday articles of commerce, such as for glazing pictures, windows, making glasses, vases and other trinkets, its properties, beyond its colour, were of little importance; and were consequently not studied. The glass then in use was what is commonly known as crown glass in some form or other, with or without the addition of colouring matter such as peroxide of iron or copper. Its density or refractive index, its dispersion, its freedom from strain, striæ, etc., were of no importance, these properties did not even receive names till glass was beginning to be used as a medium for the transmission of light and the formation of images. The use of glass in this connection dates back scarcely a century. Early in the manufacture of lens systems a second type of glass having a greater refraction and still greater dispersion, known as flint glass, was introduced to aid in the corrections that were necessary to overcome the colour errors introduced by dispersion. This glass was made in various forms, from light to heavy flint, and its properties were fully utilized by the lens maker. In far the greater majority of lenses in use to-day, these crown and flint glasses are the sole components. As the demands for more perfect instruments increased and photographers clamoured for greater rapidity, greater covering power, flatness, definition, etc., necessitating more careful corrections in the lens system, flint and crown glass would not satisfy the requirements of the necessary formulæ, for a greater variation in dispersive power as compared with the refractive index was required. In response to this demand the glass works of Messrs. Schott & Co. introduced a large number of new glasses, called Jena

Crown and flint glasses.

glasses, so named from the town in which the works are situated.

Constituents of the new optical glass.

Subsequently other firms both in England and France followed on similar lines. These new glasses with their new properties were obtained by the addition of materials hitherto unused for glass making, such as Boron, Aluminium, Magnesium, Phosphorus, Antimony, and some astonishing variations in the relative dispersion and refraction have been produced.

The following example will illustrate the difference between two glasses of different refractions.

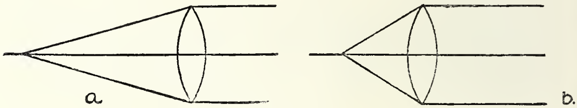


Figure 13.

Lenses with the same curvature, but different refractions.

Two lenses having exactly the same radii of curvature (figure 13, a and b), if made of the same glass, would bring the rays striking them to a focus at the same distance from each respectively. They will, however, if the one is made of glass having a refractive index of 2 and the other of 1·5, bring their rays to a focus at 3 inches from the lens in the case of the one (figure 13b) and 6 inches in the case of the other (figure 13a). It will be interesting to carry this comparison still further.

Figure 14.

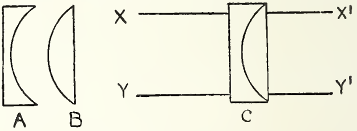
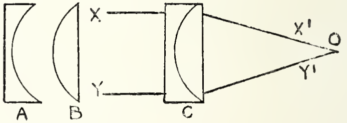


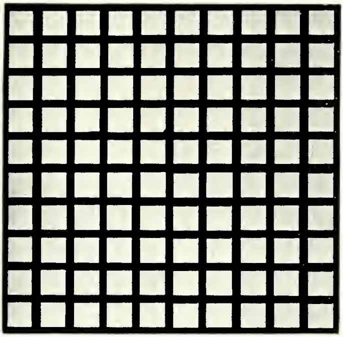
Figure 15.



In figure 14, let A be a negative lens made of

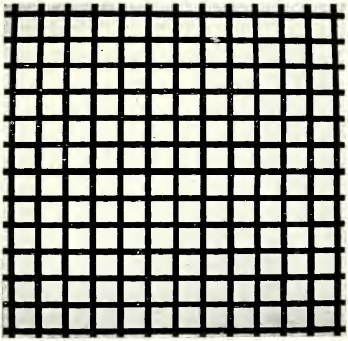
See page 75.

PLATE VII.



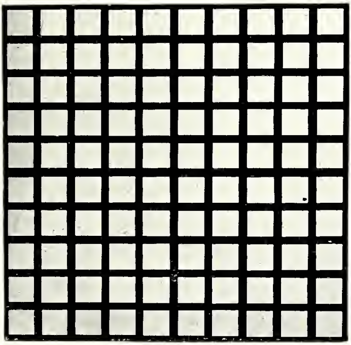
Photograph of a straight line chart, taken with an R.R. lens, showing no distortion.

PLATE VIII.



Photograph of the same chart taken with a single view lens, showing slight barrel-shaped distortion.

PLATE IX.

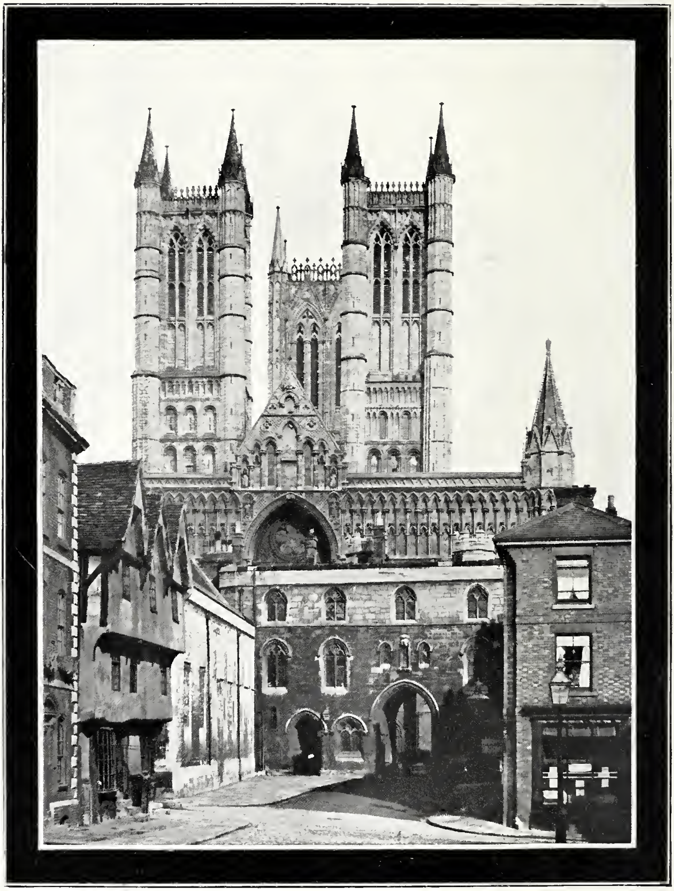


Photograph of the same chart taken with a ½-inch combination of a Beck-Steinheil Orthostigmat (single lens) showing no visible distortion.

See page 75.

PLATE X.

Lincoln Towers.



Negative by *H. Andrews.*

From a photograph taken with a single combination of a No. 8 Beck-Steinheil Orthostigmat, 11-inch focus.

PHOTOGRAPHIC LENSES

glass with a high refractive index, say 2, as in the previous case, and let it have a negative focus of 3 inches; let B be a positive lens made of the same glass of a focus exactly similar, namely, 3 inches. In order to have the same focus, as one surface of each of the two lenses is supposed to be flat, the contact curve will be of the same radius in both cases. If these two lenses are placed together as C, they will form a plate of glass with parallel sides, and the rays XX′ and YY′ will pass unaltered through it. Hence the combined lens system has no focus.

Combination of two lenses.

Now in figure 15, let A be identically the same in shape to lens A, figure 14, with the same curvature as before, but made of a glass having a refractive index of but 1·5, its focus will be lengthened (see previous example) to six inches. Let B, figure 15, be the same as B, figure 14, as to curvature, which is the same as that of A, and let it be made of the same glass as before having a focus of three inches. Place A and B together as C, and it will be found that the plane sides are parallel as before, but that the rays XX′ YY′, instead of emerging parallel, as in figure 14, intersect or come to a focus at O. This resultant focus of the pair will be the combination of a six-inch negative lens and a three-inch positive, which gives a positive lens of six inch focus. The above example serves to illustrate the differences in the character of lenses which result from the use of different kinds of glasses. In order to illustrate the point a somewhat extreme case has been taken. Glass with so high a refractive index as 1·9 or 2 is seldom used; so dense a glass cannot be manufactured with any degree of certainty in such a way that it will not tarnish on prolonged exposure to the air.

Glasses with considerable differences in dispersive power may now be obtained having approximately the same refractive power. It has been pointed out that a single lens made of one kind of glass does not bring the rays of different coloured light to the same focus and cannot consequently be used successfully for photographic work.

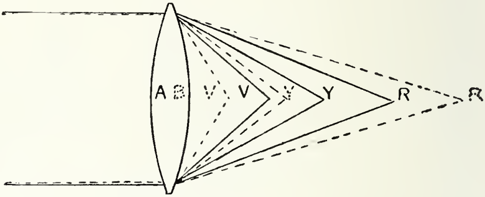


Figure 16.

Glasses having different dispersion.

In figure 16 let A and B be two lenses superimposed of exactly the same curvature and refractive indices, but let the dispersive power of A be much less than that of B. It will be found that in both instances the different coloured light will be separated and the foci for the different colours will be at different distances from the lens, but the degree of separation will be less in the case of A than in the case of B. This, therefore, illustrates a difference in dispersive power.

How these two properties are used to effect a correction for colour will be referred to and simply illustrated under the section on "corrections."

Process of glass melting.

The means whereby new glasses have been gradually discovered and worked out has necessitated great expenditure of time and money. The path is beset with difficulties. The use of certain components require that the glass be not heated beyond a certain very definite point, which is barely sufficient to allow of the materials being thoroughly mixed. If it is heated beyond this temperature the very constituents, whose presence is essential to the mixture will become volatilized and escape in the form of vapour. Some of the most useful of modern glasses cannot be kept heated to the required temperature for a sufficient time to allow the bubbles in the "metal" to rise to the surface and although a perfectly homogenous glass of this kind can be made, the presence of a few air bubbles is unavoidable.

Cause of the presence of bubbles.

There are forms of glass having valuable properties which cannot be utilized unless the glasses are cemented between other lenses, because the surfaces are subject to deterioration consequent upon the action of the air. It will come as a surprise to some to hear that certain kinds of glass can tarnish or rust almost as readily as iron, but so it is, and the optician is frequently confronted by this exasperating consideration, and has often to discard an otherwise suitable kind of glass.

Glasses that tarnish.

There are certain lenses which depend for their peculiar optical properties upon a glass which would in time tarnish if long exposed to the action of the air, but such a glass must be cemented between two other lenses insensible to climatic influence, which protect it, rendering it stable under all conditions.

One of the most interesting operations of glass making for optical instruments is the annealing, a process requiring extended time to carry out, and it is essential that this be properly done, or the glass is useless for lens making. If a molten piece of glass be allowed to cool too quickly, the surface exposed to the air will harden more rapidly than the rest, and consequently contract, putting pressure on the molten mass within. The result of this will be that different portions of the glass will have different densities, and consequently different powers of refracting light. A strain will be present in the glass invisible upon ordinary examination, but which may be detected by a polariscope. Any strain or tension will give to

Annealing optical glass.

Effect of bad annealing and test for same.

it a crystalline structure, and the black cross or the rings and brushes noticeable when examining crystals with a polariscope will betray any lack of homogeneity in the glass.

The method adopted to prevent the unequal cooling of glass is termed annealing. It is simply slow cooling, carried out in ovens the temperature of which is gradually allowed to fall, so that the whole mass of metal becomes solid at the same time. In the case of large discs it may take many weeks or months to successfully accomplish.

Colour in optical glass.

Transparency and lack of colour are important qualities of optical glass. If a piece of glass be even slightly coloured it will mean that some of the light has been stopped or absorbed in passing through it, the emergent light has been robbed of some of the series which go to make up the perfect ray of white light.

Careless handling causes stain.

Colour may be an inherent defect, or may be caused by deterioration ; if the former be the case, the manufacturer of the lens is to blame for employing it. It can be easily detected by laying the lens on a piece of white paper, when, as the light has to pass through the lens twice on its way to the eye, any colour would be readily discerned. Any considerable amount of colour noticeable in a lens is a certain indication that it is absorbing light, and that it will be less rapid than a colourless one for photography. Discoloration by time should never occur in the best lenses, as it means that unsuitable glass has been used ; nevertheless, moisture should on no account be allowed to settle on the surface of a lens, and touching the surface with hot fingers should be avoided. Discoloration of the surfaces due to any such reason can be removed by repolishing.

A minor defect in glass is the presence of small bubbles ; these are absolutely unavoidable in certain kinds of glasses where particular optical qualities are required. The subjoined cutting from a circular issued by the glass makers themselves, puts in a terse way the pro's and con's of this defect.

IMPORTANT NOTICE—
BUBBLES IN PHOTOGRAPHIC LENSES.

The efforts of opticians, during the last few years, to improve Lenses in their higher optical characteristics, have led to more extended use of glasses in the manufacture of Photographic Objectives, which differ widely in their optical properties and chemical composition from the crown and flint glass hitherto employed. Their manufacture is attended, to some extent, by far greater technical difficulties than are involved in the production of the optical glass formerly in current use. In the manufacture of the majority of the new kinds of glass which have taken front rank in the construction of improved Photographic Lenses, there are exceptional difficulties in securing perfect purity, i.e., freedom from small bubbles. The definite demands which have to be met to obtain relative dispersion and refraction differing from usual conditions, impose such stringent limitations upon the chemical composition of the glass fluxes, that no play is left to the manufacturer technically to provide suitable conditions for obtaining perfect purity. In consequence of this, it is practically impossible to supply these kinds of glass in uniform pieces free from a few small bubbles.

We would, however, point out that the presence of these small air-bubbles, even under most unfavourable conditions, does not occasion a loss of light exceeding 1/50 per cent., and their influence upon the optical efficiency of a Lens system is therefore of no moment whatsoever.

It is manifestly unfair to require that the manufacturer should reject nine-tenths of the glass which is made, simply because it shows a fault that is of absolutely no importance in practice, notwithstanding the fact that he is able to satisfy the higher demands of the optician with regard to all the really important properties the glass should possess for the functions of the lens.

If purchasers make the usual objection that a lens is "faulty" because of a few small bubbles, the optician must kindly explain that Lenses of the higher class cannot be made of any sort of crown and flint, and that more important consideration have to be taken into account in selecting the glass than the absence of a few small bubbles.

Glastechnisches Laboratorium,
Schott & Genossen.

Unimportance of bubbles.

From the above it will be seen that no notice need be taken of such defects in a high-class lens, indeed they have almost come to be known as the hall mark of a modern anastigmat. The bubbles are perfect spheres and reflect all the light back again. A simple experiment will show their harmlessness. If a half-penny be placed on the front surface of say a half-plate lens of the orthostigmat type and a gas jet be focussed on a piece of white paper, an image of the gas jet will be formed sufficiently bright to be clearly visible, now remove the half-penny and the gas jet is still in focus, but is much more brilliantly illuminated.

Chips and scratches are somewhat unimportant defects, but a perfect black polish on every surface is essential if the lens is to be worthy of the name; a grey surface fills the camera with useless light which tends to destroy the crispness of the picture. Striæ and veins in glass are serious defects which should never exist in a good lens, they point to imperfect preparation of the molten glass, it is not homogenous and must on no account be used. This defect will not be present in lenses by the best makers. Their presence is readily detected when well marked before the lens is made, but the finer varieties are impossible to discover till the lens is polished, and the ruthless destruction of lenses with veins, after time and money have been expended over their manufacture, is one of the most exasperating regular experiences in the best factories. These defects are frequently met with in cheap lenses where price makes it impossible to reject the bad ones.

Destruction of imperfect lenses.

MANUFACTURE.

Grinding.

It has already been mentioned that the surfaces of photographic lenses are spherical; elliptical, parabolic, or oval surfaces might perhaps have advantages over the spherical, but at present no method has been devised by which such surfaces can be accurately made. This will be the more readily appreciated when the method of lens grinding is described.

To grind a disc of glass it is usual to employ some material harder than the glass, in a powdered form, such as diamond dust, emery or sand. The glass is rubbed against a metal tool or mould of the desired shape with the emery, sand or other material between the surfaces. In this way the glass is gradually made to assume the shape of the tool. That an evenly ground surface may result, the movement of the lens as it is pressed against the tool, must be irregular. If by chance the glass be held stationary when the tool is revolving in the lathe, a series of circular grooves would be plowed, leaving a corrugated surface. It is necessary to give to the glass a motion like moving a ball in a socket. A little consideration will show that the cup and ball motion can only be accomplished with two spherical surfaces, ellipsoidal surfaces, for instance, can only be moved on their common axis, if they are moved in any other sense, they cease to remain in contact all over. Glass grinding tools are cup-shaped, concave, or ball-shaped convex metal tools, usually fixed to a glass grinding lathe. They are made in pairs, the one concave the other convex, so that each pair can be ground together to keep the curve true, and for every different curve to which a lens is to be ground a special pair of tools must be made. In order to construct a pair of such tools, say of 6 inch curvature, a brass gauge is first made by turning in a lathe a disc and ring

Shape of the tools used.

of brass measuring exactly 12 inches across (or 6 inches radius). The cup and ball tools are now turned to fit these gauges as accurately as is possible; after this they are ground together with emery until they fit one another. They are now spherical curves and are tested by an instrument known as a spherometer which registers the curvature. This instrument measures, by means of a micrometer screw, how far the ball-shaped tool projects through a ring of known size. If, as is probable on the first trial, the tool is not absolutely correct, a little is turned off either at the edge or the centre, and the pair are ground together again and tested till they are correct to the curve required. These tools are used for rough grinding and are not quite so carefully made as those required for the later delicate operations of fine grinding and polishing, where the greatest accuracy attainable is necessary.

Spherometer

The process of grinding.

This consists of gradually shaping the glass to the exact contour of the mould. Coarse emery is first used, till the approximate curve is obtained, then finer grades in connection with the more accurate tools till the surface is smoother and a more exact fit to the curve of the tool is obtained. The glass itself is, during the fine grinding, tested with a spherometer and the necessary changes in the tools made to produce the curvature required.

Materials used.

The method of grinding as explained above seems simple enough, but an experiment will convince the curious that skill is required to produce a true surface. The motion given to the glass must be as irregular as possible or more will be ground from one part than another. For spectacles and very cheap quality lens work, which require but a moderate degree of accuracy, automatic machines can be employed in which the motion is conveyed by means of a crank, but no automatic machine can approach the requirements necessary to

Accuracy of cheap work.

produce a good optical surface. All the best lenses, whether they are for photographic, telescopic, or microscopic work, depend on highly skilled labour and are accordingly expensive. A particular skill of touch is attained by the best hands, a certain grip indicates whether the tool during grinding, is equally in contact over its whole area, and tells how the surface is progressing. If the curves are very convex compared with the diameter, the lenses are ground singly; if the curves are shallow a number may be worked together in a block. Such lenses as spectacles whose curvature is usually slight are made in large blocks of perhaps 50 or 100 at a time, but with most of the lenses used for photography, more highly curved surfaces are essential, and they are ground one at a time or in small blocks.

Skill required by good workers.

Block working.

POLISHING.

When the lens is ready for polishing its surfaces have been rendered so smooth that they are semi-transparent. The process of polishing is similar to that of grinding, except that polishing powders, such as rouge and putty powder, are used instead of emery, and that the mould is covered with a thin layer of fine cloth or wax. The motion is the same, and is continued until gradually all the marks of the grinding are removed and a lustrous black polish is obtained.

Polishing powders.

An incomplete polish is technically known as a grey surface, and the better the polishing the less the loss of light by reflection. This is of some importance, as an imperfect polish will scatter the light into the camera to the detriment of the picture.

Grey surface.

FIGURING.

It might now be supposed that the lens was finished, and if it were to be used for a spectacle lens or cheap opera glass this would

Figuring.

be the case, but the surface is far from being sufficiently accurate for the best class of instrument. The necessity for the utmost perfection will be better understood when it is remembered that the individual components of a photographic lens are usually of almost equal and opposite kinds (concave and convex) cemented together, and that they are powerful lenses which almost neutralize one another, leaving only a small outstanding power, so that an error in a single surface when compared with the total power of the lens would be apparent. This method of balancing convex and concave lenses against each other is the only plan that can be employed to effect the required corrections. Strange as it may appear, a polished surface is often an undulating curve, the irregularities of which may not be more than a 1/100,000th of an inch, but these irregularities must be removed. No mechanical measuring appliance will discover such slight errors, but optical means dependent for their action on the interference of light enable them to be readily detected. To give some notion of the accuracy required it should be explained that a lens must be allowed to cool before being examined. If one portion of the glass happens to be slightly hotter than the other the unequal expansion is sufficient to alter the curve so much that the errors to be removed would be comparatively insignificant, compared with the new error produced by the inequality of the temperature. This is by no means an exaggeration, the cooling being a regular workshop practice. An extreme case that came within the writer's knowledge was where a large lens was allowed to cool for days before it could be tested with certainty. For a small lens from ten to twenty minutes is usually sufficient.

Perfection of the process.

The irregularities are removed by the tedious process of figuring, which is a system of local polishing with pitch polishers on specially constructed machines. When all this is considered it will be understood wherein lies the difference between simple commercial lenses and first-class optical instruments, and the large difference in price between them.

CENTRING.

A modern lens is generally made up of a number of component parts cemented together in groups. The Beck-Steinheil Orthostigmat consists of 6 lenses thus joined in two triple combinations. One of the most important features of such a construction is that the centres of all the curves must be exactly on a straight line, in other words, that the lens must be centred. To accomplish this all lenses are ground and polished to a size a little larger than will be required when finished; they are centred on a lathe until the images reflected from their surfaces are quite stationary while being revolved. The edges are then carefully trimmed with a diamond to the exact size required to fit the cell that has been prepared. The component lenses of the combination are now cemented together, finally tested and, if centred accurately, are placed in their cells. As the finest performance of a lens depends on the mathematical exactness with which the light passes through the relative portions of its curved surfaces, the least displacement of any one of the curves would destroy the efficiency of the design. The utmost care, therefore, must be used in centring the lenses to ensure the curves fulfilling their proper functions.

Edging and centring.

MOUNTING.

Without referring at length to the ordinary process of brass turning, mention may be made of a few points connected with lens mounting The cells and mounting of a lens must be absolutely true in every respect; this, of course, only requires first-class workmanship. The mount must be so designed that none of the image-forming rays are stopped by any portion, either when entering or emerging from the lens. Good instruments are almost without exception correctly made, but a shutter placed between the combinations of a lens, or behind or in front of it, unless carefully arranged, will frequently cut off some of the oblique light, thus causing unequal illumination.

Shutters between lenses.

SEPARATION OF THE LENSES.

The distance apart at which the lenses of a doublet are fixed in the mount is of as great importance as the centring; every individual lens of first grade must be separately adjusted in this respect. It is not sufficient to fix them to a standard distance, as the least variation in thickness, of the individual combinations, calls for a special adjustment in this respect. In some of the latest types of lenses, this separation is so slight that the smallest sizes do not admit of being mounted in a diaphragm shutter. For example, the Beck-Steinheil Orthostigmat lens used in the No. 8 Folding Frena is mounted in a special shutter having a wheel diaphragm in place of the ordinary iris, and this merely that the separation should not be a fraction more than the correct distance. An interesting point in connection with the mounting of photographic lenses, and one which is not realized except by those who are continually working with glass, is that this seemingly hard and brittle substance is very elastic.

Sensitiveness of good lens to separation.

For this reason a lens must not be held too firmly in its cell, or it will be twisted out of shape and the quality of its performance be impaired. The finest lenses may be rendered quite worthless unless proper care is bestowed upon this point; on the other hand, they must be held accurately in position, there must be

Mounting lenses tightly in cells.

no shake, or the centring of the system is gone. It is not uncommon in very cheap lenses to see the most inadequate provision made for fixing them in their mounts, such as a split ring merely pushed into the cell, a contrivance which would not withstand a smart jolt or shake.

Lens testing.

Before the lens is placed in the hands of the public it must pass through a most rigid series of tests. During the various processes of manufacture, unexpected errors may creep in which it has been impossible to foresee, and although much greater certainty has now been attained in the modern methods of manufacture, it is necessary that each individual lens be carefully tested.

The methods employed are described later (Appendix II.), but it must be remembered that physical defects, such as striæ, necessitate the destruction of that component of the lens in which it appears.

BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION II.

(1) Practically all lenses are made of glass in some form or other.

(2) Glass possesses 5 distinct properties of great importance—

  (1) Refracting power (refractive index).
  (2) Dispersive power (in relation to colour).
  (3) Stability under varying atmospheric conditions.
  (4) Colour of the glass.
  (5) Physical defects.

(3) Refractive power is the quality which glass possesses of bending light passing from a dense medium into a less dense, and vice versa.

(4) Dispersive power is the quality which glass has of breaking light up into its primary colours.

(5) Refractive and dispersive powers vary independently in different kinds of glass.

(6) Refractive and dispersive powers are affected by the composition of the glass.

(7) The physical defects must be avoided, as with the exception of "bubbles" they damage the quality of a lens. They are Striæ, Strain, Scratches, Chips, etc.

(8) The presence of colour means the loss of light.

(9) The loss of light means the loss of rapidity.

(10) The presence of bubbles is of no importance.

(11) The processes of manufacture are—

Grinding, Polishing, Figuring, Centring, Mounting, Testing.

(12) All these processes must be most skilfully carried out to produce the best work.

SECTION III.

CORRECTIONS.

Corrections.

That a simple lens does not fulfil all the requirements of the photographer has been already stated. That its defects can be cured wholly or in part has also been suggested, and it is the purpose of this chapter to explain in as simple a manner as possible the various errors and the extent to which they may be corrected, together with some information which may assist in avoiding those which cannot be entirely eliminated.

Aim of the section.

The careful perusal of these pages will assist the reader in comprehending the later sections concerning the advantages and disadvantages of different types of lenses. It will enable him to realize the principles upon which a lens should be chosen for any particular purpose, and what types approximate most nearly to the ideal lens.

The aim of any optical system used in photography is to faithfully reproduce in the picture every point in the object.

The property of the mirror.

Of all uncorrected systems there is only one that completely fulfils this condition, viz., the plane mirror. A point to point similarity between object and image is only accurately obtained by reflection from a plane surface. Since this reflection can produce no image, but can only change the position of one already existing, it hardly concerns the photographer. In order to produce an image it is necessary to do more than merely reflect the light by a flat mirror. The light must be bent, and it is in the process of bending or refracting the light that difficulties arise, often calling for complex systems of lenses to overcome them. The problem of constructing any instrument is dependent upon the purpose to which it is to be put. Image formation by a photographic lens may require that a large angle of view shall be included in the picture; in a microscope objective and in the telescope, comparatively small angles are dealt with; again with eyepieces and magnifying glasses, the angular breadth of the pencil may be sacrificed to include as large an angle of view as possible. When a photographic lens is to be used for enlarging it trespasses on the microscope; when used for telephotography it is bordering on the domain of the telescope, and the design of a lens must be varied accordingly. The extent of the field of view, the rapidity and the quality of definition govern the construction, and in the various types of lenses these considerations have to be taken into account. So in the portrait lens great rapidity and limited angle of view are desirable, and in the wide-angle lens, less rapidity but greater angle. A photographic lens is always a compromise, and it is the object of the optician to combine as many properties as possible in one lens.

Refraction necessitates correction.

An example of the diversity of power between two lenses is illustrated by the following comparison. Both lenses are excellent, of their particular class, but the absurdity of attempting to use one for the work of the other is evident.

Diversity of power of two different lenses.

(1) A Portrait lens 6 in. focus covers a circle 2½ in. in diameter at f/4.

(2) A W.A.R. lens 6 in. focus covers a circle 10 in. in diameter at f/16.

The various corrections necessary in lenses will be taken in the following order and explained as briefly as possible :—

(1) Chromatic aberration.
(2) Spherical aberration (direct and oblique).
(3) Astigmatism (radial and tangential).
(4) Curvature of the focal surface.
(5) Distortion.

Effect of stopping down.

All defects of photographic lenses excepting distortion may be reduced by stopping down the aperture, that is, by using the iris diaphragm, and therefore a rapid lens must be the most carefully corrected; it is in these lenses that defects are most marked. A lens that will do good work at f/16 may be useless at f/8.

(1) CHROMATIC ABERRATION.

Definition.

Chromatic aberration is an error or defect caused by the inability of a lens to converge a ray of white light coming from an illuminated point to a similar point of white light in the image.

Reference was made in Section II. to the property possessed by glass, of breaking up a ray of white light into its component parts, and by a lens of focussing the different colours to different points (figure 17).

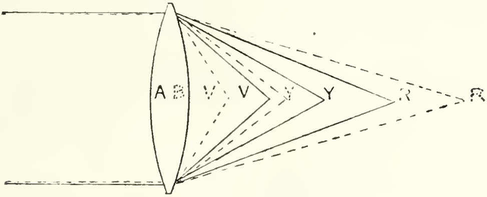


Figure 17.

This power of dispersion varies in different kinds of glass. Two lenses, A and B (figure 18), the one negative the other positive, may be selected so that A is composed of glass having double the dispersive power of B. The lens A will, therefore, displace the colours double as much as the lens B, and need in consequence be but half the power of the other lens in order that it may correct the errors. It follows, therefore, that a lens A of 12 in. negative focus will correct a lens B of 6 in. positive focus. When the two lenses are put together the combined lens C (figure 18) will still have a positive focus of about 12 in. The combined lens C is not as powerful as the original positive B, but it will still have considerable power, and it is so corrected that the image of any point of white light in the object will be represented by a similar point of white light in the picture plane.

Method of utilizing dispersion for correcting for colour errors.

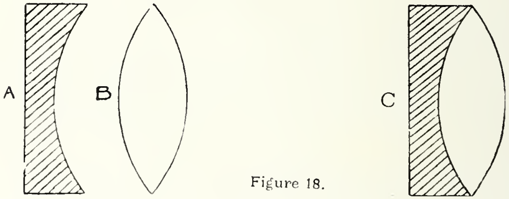


Figure 18.

This indicates the means taken to correct chromatic aberration, but as a matter of fact no lens made of two kinds of glass only, can be corrected for all colours in the spectrum. A double lens can be designed to unite the yellow and violet rays in one focal point, but in this case the red and green rays will only be partially corrected. This is due to the fact that few glasses are yet available that have proportional dispersive power.

In the simpler forms of photographic lenses such as the single achromatic meniscus, the usual method is to correct for those rays which are chemically most active (figure 19), so that when the ground glass is adjusted to receive upon it the image sharpest to the eye, it will,

Correction of two colours only.

on being replaced by the photographic plate, receive those rays which are to form the image on the sensitive surface, also at their sharpest point. Where more than two kinds of glass are used, it is possible to correct for more than two colours or lines in the spectrum, which in some special branches of work is desirable. If the image of a point produced by such a lens (two kinds of glass) be examined with a spectroscope, an appearance as shown in figure 20 will be observed; if the lens were perfectly corrected the image would appear as a straight line, the point of light being merely expanded into a line of spectrum colours. But if the lens be only partially achromatized for two colours in the spectrum, these colours only will form part of a line, the others being more or less expanded.

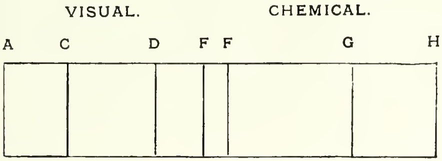


Figure 19.

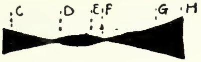


Figure 20.*

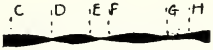


Figure 21.*

Appearance of a point viewed by a spectroscope.

In figure 21 the same is shown through an instrument such as the Beck-Steinheil Orthostigmat, where the lens is corrected for three

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The appearance has been exaggerated to more clearly illustrate the phenomenon.

colours in the spectrum and approximates to a perfect correction throughout the whole length. This is indicative of the highest type of an achromatized lens.

It will be seen at a glance that if a lens of this type be used for three-colour work there will be no need to readjust the screen between each operation for the different colours.

Descriptive plate.

Variation of relative dispersion.

The difficulty in correcting for more than two points in the spectrum is due to the fact that the relative dispersion of the two glasses for the various parts of the spectrum differs. The total dispersion of one glass may be double that of another, and lenses made from these glasses may be so arranged that the extreme colours of the spectrum are corrected, but the intermediate colours will not be so unless the partial dispersions at every part of the spectrum are also double. This so-called "irrationality" of the dispersion exists in most glass, and a strictly perfect colour correction is impossible with two lenses, although it is sufficiently accurate for most purposes. In figure 22, if A C D F G H be taken as being the chief lines in the spectrum, when a ray of white light is passed through a prism of one kind of glass, and A′ C′ D′, etc., be those of a ray passed through a different kind of glass, it will be seen that the total dispersion for the lines A and H is the same in both cases, whereas in any intermediate position they are different.

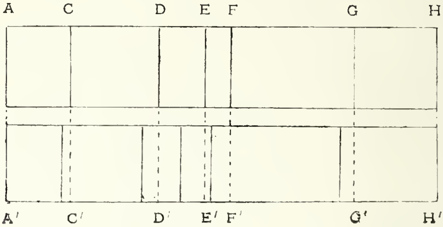

Figure 22.

Consequently if a lens is constructed of these two kinds of glass, and the coloured light represented by the lines A and H are accurately corrected, the other colours will be slightly uncorrected.

Result of using two lenses of different relative dispersions.

The correction for chromatic aberration for central rays is not the only colour correction necessary, as when this error is eliminated the marginal portions of the field might be fringed with colour owing to differences in the sizes of the images produced by the different coloured light. As the correction for this is purely a matter of calculation, it need not be more than mentioned.

The effect produced by the presence of chromatic aberration.

Effect of the colour error on the photograph.

The definition of the term chromatic aberration almost explains the direction in which it will make itself evident in the production of a photograph. If the lens in use is of some non-achromatic type and the view is focussed on the ground glass, the more brilliantly defined portions of the subject, such as a tree standing against a light background, or the edge of a building with the sky behind, will be used for focussing, and the rays producing this image will be essentially those affecting the eye most vividly, such as the yellow. The photographic plate is now placed in this plane and an exposure made in the ordinary way. As is well known, the rays that affect the plate and cause the changes in the silver salts of the emulsion are the dark green, blue and violet rays. Now, under the assumption that the lens is non-achromatic, the rays affecting the plate will not be brought to the same focus as those that were used in focussing, consequently the resultant picture will be out of focus and blurred. Hence if the lens be non-achromatic, however carefully the focussing is done, a sharp image will not result.

Chemical focus.

A lens of this type is said to have a chemical focus. There are methods, however, of overcoming this disadvantage to a limited extent.

Method of avoiding the error by calculation.

(1) Actual calculation can be made and the different focal lengths for the various colours can be found, the distance between the violet and yellow rays being noted. After the picture has been focussed by the eye, the screen can be racked forward the required amount, a distance frequently equal to as much as a ¼ of an inch. This method was regularly adopted in the early days of lens making, when the possibility of effecting different corrections was less perfectly understood.

By experiment.

(2) By experiment. First focus the object carefully, and then move the screen forwards a certain amount (which carefully note) and expose a portion only of the plate; repeat this four times, each time moving the screen slightly forward and exposing a fresh portion of the plate, and after development one section will be found to be better defined than the remainder. Now ascertain what was the position of the screen when this section was exposed, and by moving it to this position in future sharp pictures can be assured.

It will be noticed above that the screen is moved forwards, this is because in a non-achromatic lens as illustrated (figure 17), the violet rays have a shorter focus than the yellow.

By means of a blue glass.

(3) Place in front of the lens a blue glass of about the density of the blue-violet end of the spectrum, then focus the picture, when, because all but the blue rays are excluded, the focus of those rays will be given and not the yellow. If the exposure is now made, having removed the screen, a picture that is sharp will be the result. The objection to this method is that, excluding the most visually active rays, only a dim picture remains to focus by.

If the lens has been found to be non-achromatic, its general usefulness can be increased by stopping down. This allows the plate to be placed slightly out of focus without ruining the definition.

Effect of over-correction.

In lenses which are approximately achromatic the correction is occasionally carried too far, and the focus of the violet rays has been so lengthened that they come to a focus further from the lens than the yellow ones. Such lenses as these are over corrected for colour, but are seldom met with.

Example of the effect of using an uncorrected lens.

The effect of using an uncorrected lens can be gathered from plates II.* and III.* Plate II. is a photograph of a chart made up of the various prominent colours in the spectrum taken with the lens focussed for the black lines on right of centre, no adjustment being made for the violet rays. In plate III. an adjustment was made, and the plate was set in the best possible position at the chemical focus of the lens. The difference between the two results is clearly shown by the two plates. Further points to be noticed are that in plate II. the sharpest lines are those between A and D, which were either yellow or red, and the worst are the violet. The photographically useful are bad and the photographically useless are good. In plate III. the worst are the red ones. These results are what might be expected (see pages 29-30).

Effect of adjusting the plate to the chemical focus.

In a general way, when non-achromatic lenses are sold they are supplied either in box cameras or in focussing ones with scales, and no focussing upon a ground glass is possible. In these cases the makers adjust the scales to the chemical focus, and the best results of which they are capable are obtained. A large aperture cannot be used with such a lens, as the definition is only good provided a moderate stop is used. The possessor of one of these instruments may be misled if he places a ground glass in the camera and imagines from his experimental trials that the scale is incorrect.

Alteration of scales necessitated by the use of these lenses.

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*Without an exception the lenses used to illustrate this book are existing types now being sold, and are not specially made to exaggerate defects.

This correction has been treated of at some length, and referred to—first, because it was early recognised as being of great importance, and the construction of high-class optical instruments dates from the time when the way to correct for this error was discovered. Newton, in dealing with telescopes, considered achromatization impossible; but Dollond, early in the 19th century, discovered the solution of the difficulty, and produced an achromatic telescope objective. This objective in itself is not suitable for photographic purposes as it only includes angles of 2 or 3 degrees, whereas in photography angles up to 100° may be required; nevertheless, it demonstrated the method by which the achromatic correction could be made, and gave an immediate impetus to instrument making, which led to the invention of the Achromatic Microscope and numerous types of Photographic Lenses.

First achromatized lens.

Any lens that is non-achromatic may be considered as being at the very bottom of the scale; it is useless for rapid work or copying pictures, paintings, etc., and is only worthy of attention on account of its extremely low price. The ordinary spectacle lens is a typical example of this class, and may be recommended to the notice of those searching for those unreal, fuzzy reproductions admired by some of the modern schools of "art."

Uses of non-achromatic lenses.

A lens of the spectacle type possesses other errors, in fact, most other errors, to a greater or lesser degree. The double meniscus non-achromatic lens is partially corrected, but in general a lens that is not corrected for achromatism is not corrected for anything else.

SPHERICAL ABERRATION.

Spherical aberration is due to the use of spherical surfaces, which are the only form that can be accurately ground.

Definition.

It may be described as the inability of a lens to convey the marginal (not oblique) rays to a point at the same distance from the lens as the central rays.

Description of aberration.

To put the case in another way, the rays passing through the edge of an uncorrected lens do not focus to the same point as those passing through the centre (see figure 23). The term is usually confined to direct rays, to the light which forms the centre of the picture and not to the margin. When oblique rays are considered the error is known as coma or zonal aberration.

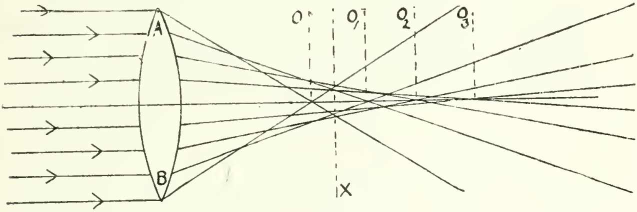

Figure 23.

Appearance caused by presence of spherical aberration.

If figure 23 be examined, this aberration will be more readily understood. A B represents a lens receiving a beam of light from some distant luminous source. The central cone of rays is brought to a focus at 03, the next series of rays outside the centre are brought to a focus at 02, and the marginal still nearer the lens at 0; from this it is obvious that the lens has no absolute focus, anywhere between 0 and 03 might be taken as the focus according to the particular rays considered. If this phenomenon be examined by placing the focussing screen at different positions along the axis, the effect caused by the error may be observed. Suppose that the screen be placed in the plane of 02, it will be noticed that there is a central, bright and luminous point surrounded by a gradually fading circle of light, the latter due to the marginal rays;

when the screen is moved to 01 and examined, a smaller and more evenly illuminated circle will appear, in which the centre and edges are the faintest. When the screen reaches X the circle of illumination will be the smallest size attainable with the lens under consideration, the circle at this point is called the circle of least confusion; this would be the most satisfactory position at which to place the screen for photography. It is the position where the image of a point is as nearly a point in the picture as the lens can produce.

Circle of least confusion.

Now move the screen to O, the focus of the marginal rays; the circle will have again increased in size with a bright centre and a bright margin. The appearances are diagrammatically represented in figure 24.

Appearance of a point with the screen at different positions.

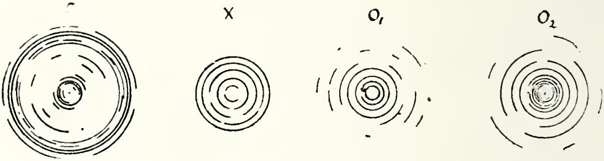

Figure 24.

It is scarcely necessary to explain that if a lens produces a picture of a point as a circle it cannot give a brilliant image. Every object is a large number of separate points whose images, if consisting of circles, will overlap one another and produce an indistinct and blurred picture.

There are two kinds of spherical aberration, known as positive and negative. It is by the combination of these two kinds in different lenses that a correction is made. The amount of spherical aberration present in a lens is governed by its form or shape, and it is quite possible to construct lenses of the same power, but of different forms.

Positive and negative spherical error.

Considering parallel rays, it may be taken as a rough guide that for plano or double convex or concave* lenses of the same focus, the greater the curvature facing the parallel rays the less the spherical aberration.

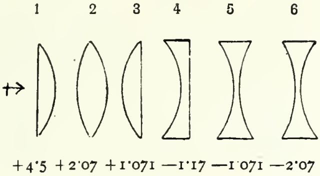

Figure 25.

In figure 25 are given some numerical examples of the amount of aberration present in certain forms of positive and negative lenses. Nos. 1 and 3 represent the same lens turned round, and the difference in the error is very marked.

Method of correcting spherical aberration.

No single lens with flat or spherical surfaces is free from this aberration; it cannot, therefore, give a sharp image unless stopped down so that its centre only is used.

The method of correction for spherical aberration consists of combining two or more lenses, so that the negative error of the one may correct the positive error of the other. Chromatic aberration, it will be remembered, was corrected in a similar manner, namely, by balancing two or more lenses with equal and opposite errors. To effectually correct for the chromatic error it is only necessary to make the lenses with certain definite relative foci, proportionate to their dispersion.

A lens can be made of a definite focus in many different shapes, so that it is possible to take two lenses, of the necessary foci to correct the colour, and to make them of the required shapes to correct for the outstanding spherical aberration. Thus in one pair of lenses both these errors may be corrected, because the colour correction depends upon their foci and the spherical aberration on their shapes.

---

* This does not apply to meniscus lenses.

Two types of single lenses.

When using the two kinds of glass most in vogue, flint and crown, the shape commonly employed for telescope objectives (figure 26) gives, when its convex side is turned towards the light, sharp images over a small field, because it is corrected for spherical and chromatic aberration. If it is reversed it gives an image less well defined, but over a larger area. This latter property is required in a photographic lens. Figure 27 is a meniscus lens with its concave side turned towards the light, and this gives better definition over a larger field than the lens figure 26.

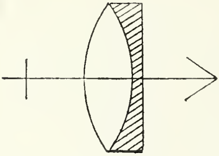

Figure 26.

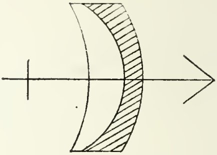

Figure 27.

Figure 27 is a type of a cheap single lens largely used in hand cameras, but as the spherical aberration is not so well corrected as figure 26, it only allows of the use of small apertures, but nevertheless gives excellent results.

A rapid rectilinear lens consists of a pair of meniscus lenses placed at some distance apart with their concave surfaces facing one another.

The principle of the correction for spherical aberration has only been lightly touched upon, and the shapes figured must not be regarded as the only ones at the disposal of the optician. Many different curves may be used, the shape of the lenses depending upon the optical properties of the glass chosen.

The effect of the error when present in a photographic lens :—

It was seen in figure 23 that there was no position in which the focussing screen could be placed, where the image of the luminous point was represented by a sharp dot. What constitutes a sharp dot may be taken to be a circle which, when viewing the picture at a convenient distance, does not subtend to the eye an angle of more than one minute. Thus, a dot 1-100 of an inch in diameter in a quarter-plate print might be considered as a point, and a lens that will reproduce a luminous point as a dot not more than 1-100 of an inch in diameter may be said to yield a sharp picture. Lenses that are only capable of the above will not produce pictures that will bear minute scrutiny or much enlargement, they cannot be used for the finest work or for photographing the most delicate detail, though they will produce satisfactory photographs of a landscape or general view. In the ordinary way a photographer will expect his negatives to bear a magnification of 3 diameters without breaking up; to allow of this, spherical aberration should be reduced to a limit, where the circle of least confusion is not more than 1-200 of an inch in diameter.

A standard of sharpness.

The original from which plate IV. is made is free from this error to at least this extent, showing what can be obtained with a good single achromatic lens.* Plates IV. and V. are two results of the same subject obtained with two lenses of this type under identically similar conditions, indicating the difference caused by bad calculation or workmanship. The inferiority of a single spectacle lens will be observed. This is largely due to the presence of spherical aberration which cannot be corrected in one

Uselessness of a single uncorrected lens.

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* A single achromatic lens, sometimes wrongly termed a single lens, consists of two or three lenses cemented together, and must not be confused with a single lens which consists of only one glass.

lens. There are cameras possessing such lenses on the market, and they should be regarded purely in the light of toys.

Remedy for spherical aberration.

Spherical aberration can always be reduced by the introduction of a small stop which cuts out the rays that are responsible for this error. A very small amount of spherical aberration may be an actual boon to the photographer under certain circumstances, but this is discussed under "Depth of Definition," Section IV.

ASTIGMATISM.

Definition.

Astigmatism is an error which only exists in the bundles of rays passing obliquely through a photographic lens. It is the effect caused by a lens converging the oblique light to two focal lines instead of to a single point.

Difference between spherical error and astigmatism.

Spherical aberration is concerned with the central area of the field while astigmatism affects the marginal definition. Spherical aberration of the oblique rays may also exist, but it is of less importance. It may be investigated in mathematical treatises under the titles of coma and zonal aberration.

Astigmatism of the eye.

Astigmatism, as referred to in connection with photographic lenses, should be kept distinct from the same word used in reference to the eye. In this latter case the term astigmatism is applied to the property possessed by cylindrical lenses of bringing the rays emanating from a bright object to a focal line in distinction to a focal point. It is a property taken advantage of when correcting errors in the shape of the human eye, and does not concern the present subject.

The focal lines.

Where astigmatism is present in a lens the oblique rays, instead of converging to and passing through a focal point, pass through two focal lines at right angles to one another. The distance between these two lines is the measure of the degree of astigmatism. The nearest approach to a point is at a position between these two lines where a section through the rays is nearly circular; this is called the "circle of least confusion," and may, if the outstanding error be small or the rays not very oblique, be sufficiently minute to be considered a point. When it is so, the lens may be regarded as being corrected for astigmatism, and as being orthostigmatic or anastigmatic.

Circle of least confusion.

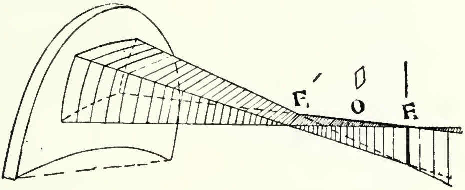


Figure 28.

Figure 28 is the usual diagrammatic representation of astigmatism, F^1 is the first focal line and F^2 the second, while midway between, lies the circle of least confusion 0. In the diagram a square bundle of light has been taken to more clearly illustrate the error, and strictly speaking, this would give a square of least confusion—square bundles of light are not met with in practice. If all the circles of least confusion were on a plane at right angles to the axis (i.e., where the plate would naturally be placed), it might be possible to obtain a fairly sharp image. In most lenses they lie on a surface curved towards the lens, and when this is so it is clearly impossible to place the plate in a position to receive even a relatively sharp image over the whole plate. It is the lens maker's object, when dealing with this error, to effect a correction which, if it does not actually combine the two focal lines in a focal point, is so arranged that the circles of least confusion are as small as possible and fall on a flat or approximately flat plane; and

Diagrammatical representation of astigmatism.

this over as large an area as possible. In the amount of success attendant on these efforts, lies the difference in lenses with respect to this correction.

Correcting for astigmatism at the same time as other errors.

The correction for astigmatism is made by the arrangement of the curves and thicknesses of the component lenses. It can be made without damaging the corrections for spherical aberration and achromatism, but a lens fully corrected for these three errors will almost always consist of three component lenses. If the properties of glass could be still further increased in the differences between their refraction and dispersion, it might be possible to construct a lens consisting of a cemented pair only, which should be free from these three errors.

The effect of astigmatism in the photographic lens:—There are few photographic lenses on the market in which some trace of this error cannot be found, provided they are sufficiently carefully tested at full aperture at the margin of the field. In the best orthostigmats or anastigmats the error is, however, infinitesimal.

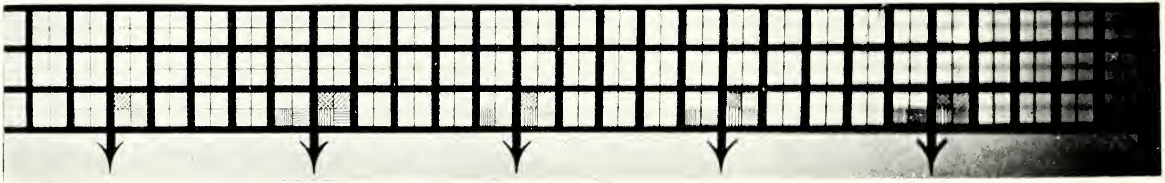
Appearances caused by astigmatism.

The practical result produced by astigmatism in a picture is a lack of sharpness at the edge, but this is accompanied by a curious appearance. Instead of the rays being brought to a focal point they are brought to two focal lines (see figure 28) at right angles to each other. A consequence of this will be that pictures of vertical lines will be brought to a sharp focus at one of the focal lines, and pictures of horizontal ones at the other. Suppose the screen of the camera to be placed in the position of the first focal line, now place a cross in the position previously occupied by the luminous point. All points in it will be represented by vertical lines (really very attenuated ellipses), and the result will be as figure 30a, the vertical line being approximately

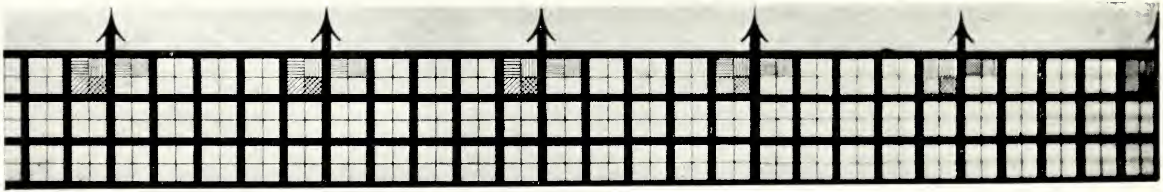
See page 110.

PLATES XI., XII., & XIII.

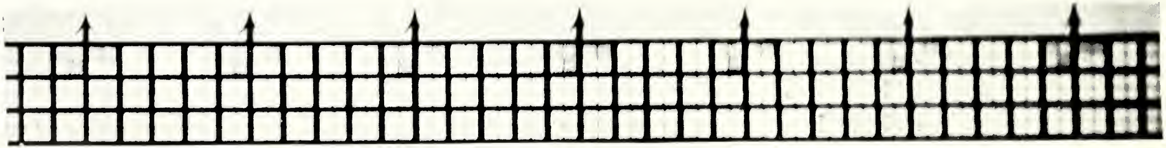
CENTRE OF FIELD (one half of the photograph only is shown).



Photograph of a test chart taken with a $8\frac{1}{2}$-inch Single Achromatic Lens, f/11.



Photograph of a test chart taken with $5\frac{1}{2}$-inch R.R. Lens, f/8.

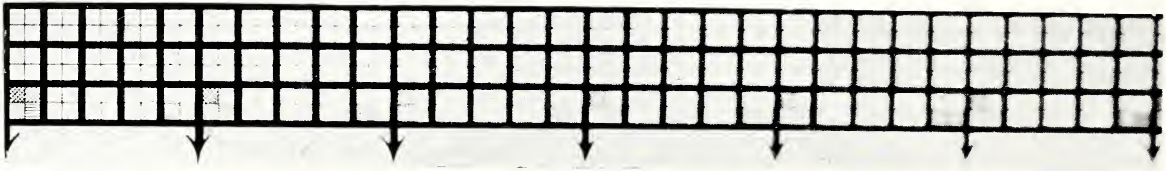


Photograph of a test chart taken with an inferior rectilinear at f/8, removed from a camera on the market.

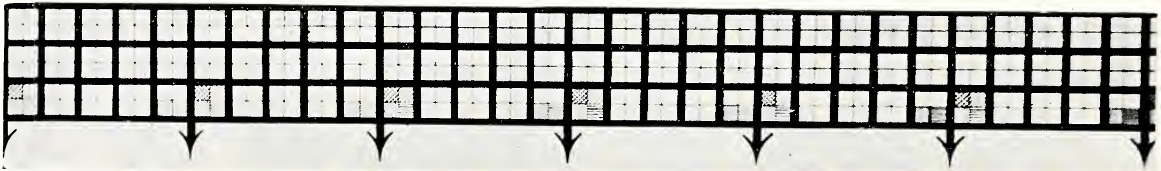
See pages 111 and 113.

PLATES XIV., XV., & XVI.

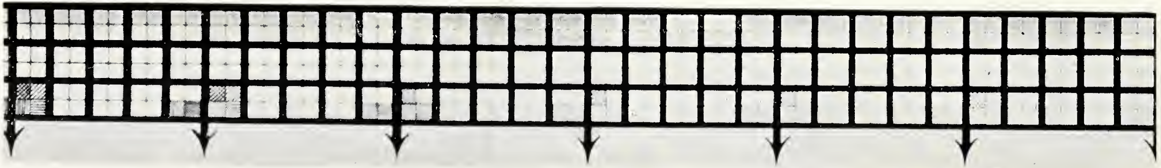
CENTRE OF FIELD (one half only of the photograph is shown).



Photograph of the test chart taken with a single lens, with stop close to the lens.



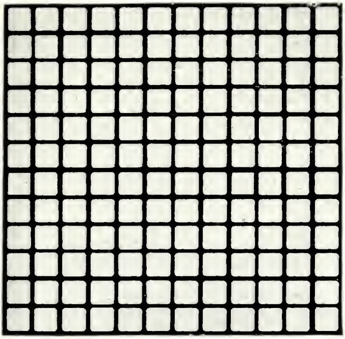
Photograph of the test chart taken with the same lens, only with its diaphragm removed to 2 inches from the lens.



Photograph of the test chart taken with the same lens stopped down to f/32, but with the diaphragm close to the lens.

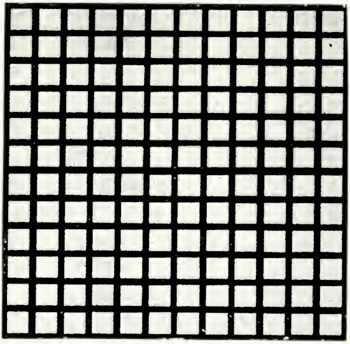
See pages 112.

PLATE XVII.



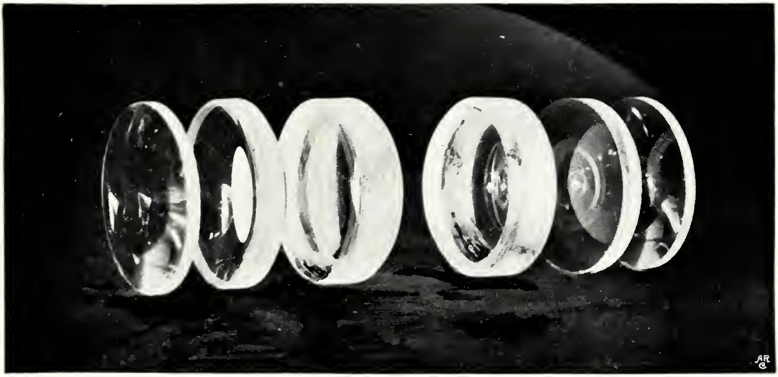
Centre of the field of a 20-inch R.R. Lens, showing slightly thickened corners at the crossings of the lines (magnified twice to increase error).

PLATE XVIII.



Centre of the field of a 7-inch R.R. Lens showing critical definition (magnified twice).

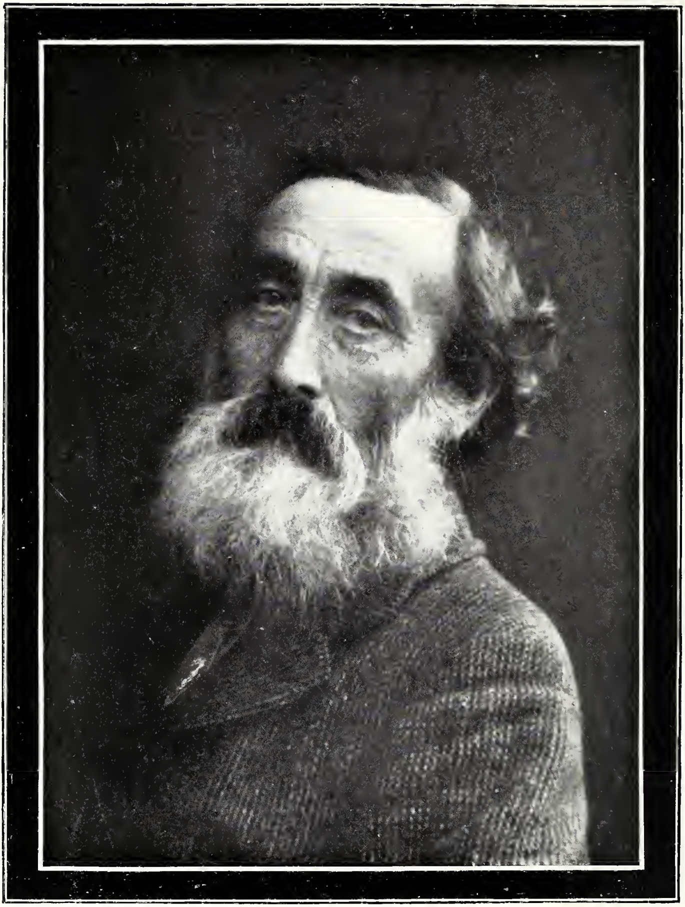
PLATE XIX.



An uncemented Beck-Steinheil Orthostigmat, showing its six components.

See page 163.

PLATE XX.—A PORTRAIT.



Negative by *B. Bishop.*

Taken with the ½ combination of an 11-inch Biplanat at f/8. Lens focus 22 inches. (In the Edition de Luxe this is a photogravure frontispiece.)

sharp and the horizontal line broad and blurred; the vertical one will be slightly longer than it should be and slightly shaded off towards the ends. Now adjust the screen so

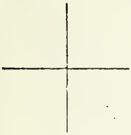


Figure 29.

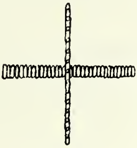


Figure 30a.

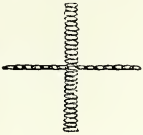


Figure 30b.

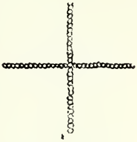


Figure 30c.

that it is in the position of the second focal line, that is at right angles to the first, and the cross will now be represented as shown in figure 30b, having its vertical member blurred and its horizontal one sharp. None of them are accurate representations of the original cross (figure 29), and give only an imperfect picture.

Nomenclature of astigmatism.

The circle of least confusion lies between the two points, and if the screen be placed in this position figure 30c will result. This is the compromise most usually accepted where astigmatism cannot be entirely removed, as it gives the truest picture the lens is capable of producing. The two focal lines are called the "radial and tangential" focal lines, one being radial to the axis of the lens, and the other at right angles, or at a tangent to the surface of the lens.

Circle of least confusion.

The plane containing the circles of least confusion, 0 (figure 31), in most lenses curves

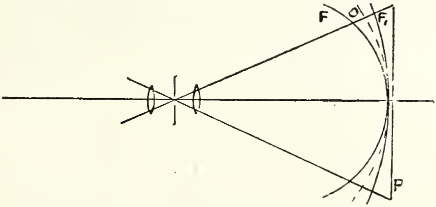


Figure 31.

inwards. Hence if F and F^1 are the two focal lines and P the plate, the probability is that F^1, the focal line furthest away from the lens, will fall on or near the plate. If astigmatism is markedly present, as illustrated, it will be noticeable in the lines pointing towards the centre of the field, these having a blurred appearance. In a landscape, trees at the edge of the field will have their trunks about as sharp as those in the centre, while their branches will not be so.

In architectural work where straight lines abound, astigmatism is a serious drawback when it is present to any considerable extent, and it is impossible to get both horizontal and vertical lines sharp at the same time. In the simpler forms of lenses astigmatism commences to show near the centre of the picture, the radial and tangential focal lines begin to separate rapidly, and continue to become more widely divided as their distance from the axis increases, and large apertures cannot be successfully used.

Figure 106 (Section V.) is a diagrammatic section of the field of a good single lens with an aperture of f/11.

Figure 110 (Section V.) shows the field of a good R.R. lens at f/8. In this case the separation is less rapid, and does not begin till it is some 15 degrees from the axis.

The minimum of astigmatism.

In figures 114 and 115 (Section V.) is shown the field of the Beck-Steinheil Orthostigmat, taken from actual measurements of a No. 3 lens $4\frac{3}{4}$ inches focus at full aperture f/6·3, in which the two focal lines are in union for the greater portion of 60 degrees, and then separate but slowly to 70 degrees and more rapidly beyond this. As compared with the previous types, its great covering power is obvious. It is an example of the point to which this correction has been brought by design and skilful workmanship; if this lens is used on the plate for which it is listed no astigmatism will be present even at f/6·3.

Practical tests for astigmatism.

To further illustrate these points plate VI. may be referred to. A, B and C are from photographs taken with three of the most widely used anastigmats of the day, of the same test; C is with the Beck-Steinheil Orthostigmat. These tests are as nearly fair as possible, the lenses being of approximately the same focus and the aperture being the same in both cases, namely, f/6·8. The freedom from astigmatism is particularly noticeable, in fact, astigmatism may be considered as being perfectly corrected. Plate VI. also shows that it is not till the marginal portions are highly magnified that this error is apparent.

To sum up, astigmatism is an error or defect which may ruin the covering power of a lens, it is absolutely prohibitive to successful results in certain branches of work, notably in architecture, copying and enlarging, unless small stops are used. It is present in all the cheaper forms of lenses, and prevents their use on large plates with large apertures.

CURVATURE OF FIELD.

Definition.

Curvature of field is the error caused by the focal plane being curved instead of flat.

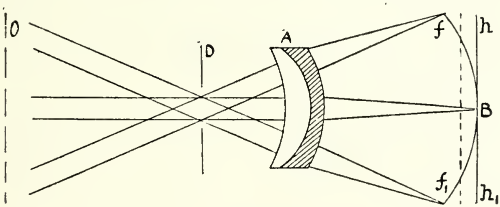


Figure 32.

Suppose A (figure 32) be a photographic lens possessing this error, D being its diaphragm or stop, O the object plane and FF′ the image

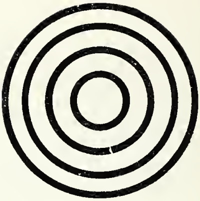


Figure 33.

Diagrams of curvature of field.

plane, or the position where the focal points lie, and HH′ be a plane at right angles to the axis. It will be seen that the marginal rays from the edges of the object are brought to a sharp focus at F and F′, while the central rays are brought to a focus at B. The curve FF′ will represent the surface on which the images of all the points in the object are situate; if this be viewed for a moment as a solid, it will take the shape of a saucer (figure 34).

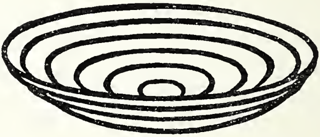


Figure 34.

The effect of a curved field:—Although the experiment has been tried, it has been found that a photographic plate of a saucer shape is impractible, and it is obvious that a flat plate can be put nowhere on the right-hand side of the lens A (figure 32), so as to receive all the points lying in FF′.

Different appearances of a test object.

If the object under consideration be a series of concentric circles (figure 33) and the plate or screen be so placed as to cut FF′ at B, the appearance of the object would be as figure 35, the only sharp portion being the central area, the definition of the image becoming worse as the centre was receded from. If the screen, however, be placed to cut the saucer in FF′, the appearance would be as figure 36 when

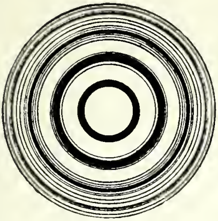


Figure 35.

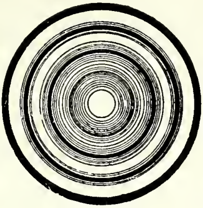


Figure 36.

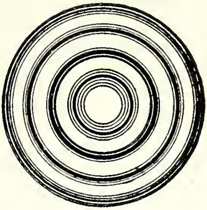


Figure 37.

the external ring is sharp, the definition becoming worse towards the centre. The position at which the best average definition would be procured would be midway between these two positions, as indicated by the dotted lines in figure 32, and the appearance would be as figure 37, where the outer circle was poor, the middle good, and the inner again poor, but none extremely bad. It is possible to have a curvature of field that is just the reverse of that which has been discussed; it has been, so to speak, over-corrected, and the field is convex towards the lens instead of concave.

Astigmatism and curvature combined.

The explanation that has been given is not quite so simple as one would be led to suppose, because it has been assumed that the lens was free from astigmatism. When this is present there is not just one plane at FF′ (figure 32); where the light is brought to a focus there are three planes, one of which is the position where the horizontal lines come to a focus, a second where the vertical lines are depicted, and a third intermediate between these two, where the circles of least confusion lie. In dealing with curvature of field it is customary to refer to this last curve as if it were the focal plane.

Focal plane.

To overcome this error when present in photographic lenses:—It is an easy matter for the photographer to determine whether it is present to any disagreeable extent. If a sheet of printed matter be focussed with the full aperture of a lens so that the centre of the field is sharp, and then the edge be focussed the alteration made will represent the amount of curvature present and the direction of the movement will indicate whether the curvature is saucer-shaped or the reverse. The simplest manner of correcting the error is by using a small stop, but a badly adjusted lens may be sometimes improved if the separation of the combinations is slightly altered, particularly if the lens suffers from a want of flatness of field while the marginal definition is still good. If the subject will not allow of the lens being stopped down, the best average position for the ground glass must be found, and the exposure made under these conditions.

Test for astigmatism.

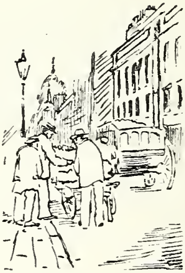


Figure 33.

A use for curvature.

Figure 38 shows a street scene in which the curvature of field being saucer-shaped, as it usually is, can be made of distinct advantage. The houses on the right and the figure on the left being nearer to the camera than the houses in the centre of the plate, come to a focus which is longer than that of the central portion of the view; the curvature of the field only enhances the effect of the whole by throwing up the figure in the foreground. It will always well repay a photographer to ascertain the amount and direction of curvature. For copying, enlarging and definite flat field work an absence of the error is essential, and the best modern lenses, such as the orthostigmat, have an almost perfectly flat field (see figures 114 and 115, Section V). A useful rule may be here given: always focus for a point to the right or left of the centre equivalent to about ¼ the length of the plate. This will give the best average focus where curvature of the field is present.

DISTORTION.

Distortion in a photograph is due to three principal causes, of which one only is due to the lens. The other two, viz., exaggerated perspective and the falling together of vertical lines are treated of later.

Definition.

This distortion is its inability to reproduce the straight lines in the object as straight lines in the picture.

Nomenclature of non-distorting lenses.

It is a very objectionable form of error if the lens is used for either architectural or line work. An image which is completely free from distortion is sometimes called "orthoscopic," or true as regards perspective, and a lens that will produce such an image over the whole field for which it is employed is commonly known as a rectilinear lens.

In a pinhole no distortion occurs, as the light travels in unbroken straight lines from object to image. In a lens, however, the principal rays suffer a deviation in their course while passing through it, and care must be taken that the alteration in their direction takes place upon a definite principle, if a non-distorted image is to be realized.

All single lenses, whether simple or compound, with the diaphragm in front or behind the system possess distortion to some degree.

A simple diagram will help to explain the cause of the defect. Let A (figure 39) be a

Diagrammatical explanation of curvature.

simple lens and BC its diaphragm aperture placed in front of and at some distance from its surface. Let a small bundle of light coming from a distant object pass through the aperture of the diaphragm B C and fall on the lens, whence it is refracted to a focus at O. Let XN-N'Y be parallel lines drawn through the nodal points* of incidence and emergence of the lens system. Let Y be the point on the picture plane OY, where the line N'Y intersects. This point Y is the true position for the rays to arrive if no distortion were present. But it is known that a simple lens (bi-convex) refracts the marginal rays more strongly than the central ones. And as a stop in front of the lens makes the oblique rays pass through the margin instead of the centre of the lens, the image, instead of lying at Y, is found to lie inside this at O, a distance OY from its true position, and the picture will, therefore, be curved in towards the centre.

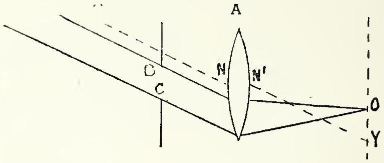


Figure 39.

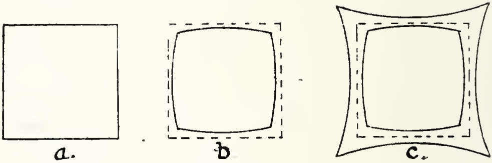


Figure 40.

Experimental test for distortion.

If this be tried experimentally with a test image of the kind indicated in figure 40a, a result similar to 40b will be obtained. If, however, the diaphragm be placed on the reverse side of the lens, namely, between it and the image, an appearance like 40c will result. These two types of distortion found in single lenses are known as "barrel" and "pin-cushion" distortion. It will be found that the further the diaphragm is away from the lens the better will be the definition, but the more marked the distortion, while the nearer it is brought to the lens the less will be the distortion and also the poorer the definition.

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* See Appendix I. on Gauss Planes.

Barrel and pin-cushion distortion.

The reason for this is simple. If the diaphragm be placed on the surface of the lens the distortion will be eliminated, because the former marginal rays will pass through the nodal points or, in a thin lens, the centre, and a true representation of the object would result. The central rays pass through the same portion of the lens as the oblique, but when the diaphragm is at a distance from the lens, as in figure 39, the oblique rays pass through one portion of the lens and the direct or central rays through another. One of the most commonly employed means of reducing this error is to alter the position of the diaphragm, but the advantage gained will probably be at the expense of the marginal definition. However, it may be found that the diaphragm is not in the best position, and a slight alteration may have a beneficial effect. Single lenses are usually turned out in large numbers at a price that precludes the possibility of much individual adjustment, and the possessor of such may find his time well repaid by examining the position of the diaphragm.

Effect of the alteration of the position of the diaphragm.

The class of lens known as the rectilinear, anastigmatic (orthostigmatic), symmetrical, etc., are entirely free from distortion when made by good makers. The method employed for correcting distortion in these cases is to combine two similar but opposite errors. It has already been pointed out that if the

Lenses free from distortion.

diaphragm is placed in front of the lens, negative distortion results, while if behind it is positive.

One method of correcting distortion.

In figure 41, let A and B be two similar lenses, and D the diaphragm midway between them. If B were removed, the image of a square (a, figure 42) would be reproduced with a certain definite amount of distortion of a positive or barrel kind (b, figure 42), while if A were removed there would be an exactly similar amount of negative or pin-cushion distortion (c, figure 42). As it is, however, the pin-cushion distortion due to B and its diaphragm D, is exactly obliterated by the barrel distortion due to A and its diaphragm D (figure 42c). As the distance between the diaphragm D and A and B is the same in both cases, the distortion is equal and opposite (dotted lines, figure 42c).

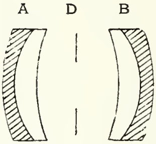


Figure 41.

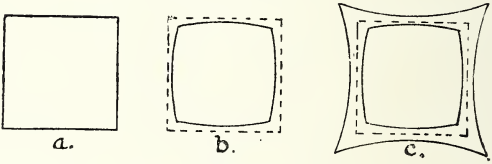


Figure 42.

If B (figure 43) is a shorter focus lens than A, the diaphragm would have to be nearer B

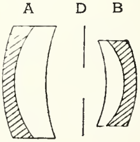


Figure 43.

than A to effect this correction, and this position bears a definite and relative ratio to the foci of A and B. It has been found in actual practice that the barrel is the least objectionable form of distortion, and single lenses are mounted with their diaphragms in front of the lens, although the question of distortion is not the only one that makes this advisable. When a single combination of such a lens as the Beck-Steinheil Convertible Orthostigmat is used alone it should always be placed behind the iris diaphragm.

Influences the edge of the field only.

The effect of distortion :—Distortion caused by the lens does not exist in the centre of the picture, it is purely an error of the oblique rays ; nevertheless it may, in bad cases, commence to be apparent in lines not far from the centre, and stopping down the lens will not improve matters.

It is present in all lenses of the single type, and in certain forms of portrait and telephoto lenses.

Plate VII. is a photograph taken with a rectilinear lens showing no distortion, while plate VIII. is one taken with a good example of a single lens. It will be noticed that the distortion is only slightly marked, although the chart was placed so as to include the edges of the field.

An example of an architectural photograph taken with a single lens.

Plate X. is a photograph taken with a single combination of the Beck-Steinheil Orthostigmat of 20 inches focus on a 12 × 10 plate and reduced for reproduction, to the size shown ; on examination it is hard to detect any trace of distortion. Such a photograph shows that the single lens, if carefully constructed, is so good that it can be used for architectural or line work, provided a long focus is chosen. In the photograph in question, plate X., the centre only of a large field 36 inch in diameter was used. The diaphragm was only an inch away from the lens, whereas in an ordinary single lens of that focus it would have been some 3 or 4 inches distant. The loss of definition due to the proximity of the diaphragm was made up for by stopping down.

For landscape work and ordinary genre studies a certain amount of distortion is not a serious drawback, as a slight bending of trees at the edge of the plate or a defective horizon does not appear false to nature. When distortion of a disagreeable kind is present it can be eliminated by enlarging, if the lens with which the picture was taken be used as the enlarging lens. The side of the lens which pointed to the view must point to the enlargement, and the error will be corrected.

FLARE AND FLARE SPOT.

Flare and flare spot can hardly be classified under the some heading as the foregoing errors. They have no reference to the formation of the primary image. A lens may be badly corrected for all aberrations and yet be almost entirely free from flare, while on the other hand a perfectly corrected one may possess the worst kind.

Definition.

Flare or flare spot is caused by the transmission of light through the lens which does not take part in the formation of the image. This may be due to imperfect mounting or to reflections from the surfaces of the lens itself.

Causes of Flare.

In the former case it is a mechanical defect, and there is no excuse for its presence. An examination of the interior of such a lens as the rectilinear will show that there is a portion of the tube lying between the lens and immediately in front or behind the two combinations, which is blackened. If this were not the case, light entering the lens would be reflected by these bright portions and be diffused over the field, thus destroying the brilliancy of the picture. Flare will occur if the blackening of this portion of the mount is imperfect, or becomes so by continued use. If the interior of the mount is screw-threaded, care should be taken that it does not rub bright, as it is easy to remove the black from the top of the threads by cleaning the lens. Should this happen the lens must be reblacked.

In the case of modern orthostigmats (anastigmats) where the separation is very slight, there is little danger of this occurring provided the edges of the combinations themselves are well blackened before they are put into their cells, but if by some chance this has been overlooked, the lens should be returned to the makers.

Points giving rise to flare.

There are fixed focus cameras on the market with single lenses where there is no actual mount, the lens forming an integral portion of the camera. Flare spot may occur in these cases if the makers of the cameras do not understand the properties of lenses, as such apparently trifling matters are liable to be overlooked. To ascertain if flare is present remove the back of the camera, open the lens and look through it towards the light, carefully examine the lens to see if any of its setting or portions of the shutter show bright; if there is no sign of such brightness there will be no flare from this cause. The second and most important form of flare is present to some extent in all lenses, however perfect, and is due to the lens itself. No lens can be constructed which does not give two images of a bright light or luminous body placed in front of it. One of these is the chief image at the principal focus and goes to form the picture, but there is another, extremely faint as a rule, on the axis and usually close to the lens surface.

Examining a lens for mechanical flare.

Optical flare.

Position of the secondary image.

This can be tested by using a hand magnifying glass, and focussing a lamp flame or gas jet on a piece of ground glass: there will of necessity be the bright image at the principal focus, but also if the glass is brought close up to the lens a faint secondary image of the gas flame will be found surrounded by the bright disc caused by the principal image out of focus.

This is an image formed by certain of the rays not passing immediately through the lens, but being reflected forward by the second surface and on to the first surface, which reflects them back through the lens. In a photographic lens the incident pencil of rays is limited by the diaphragm, and consequently the flare spot due to reflection may be considered as an image of the diaphragm. If the focus of the secondary image happens to be situated at the same distance or very nearly so, as the primary image, a definite spot will be formed on the photographic plate and entirely spoil the picture.

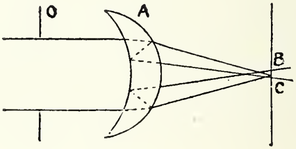


Figure 44

For example, in figure 44 let A be the lens, O the diaphragm, and let a bundle of light pass through O to A and be brought to a focus in BC, some of the light is reflected back by the second surface of A, and returns to the first surface where it is again reflected; this time it passes through the lens A and reaches the plate between B and C.

Effect of the position of the diaphragm.

In the case of an extremely thin lens it would be no use moving the diaphragm, but in the ordinary landscape lens a slight alteration in its position will sometimes cure a flare spot by distributing the false image over the whole field. Figure 45 is a diagrammatic representation of this. The spot BC is so broad that it will be of no consequence.

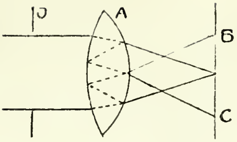


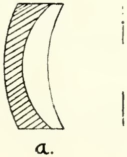
Figure 45.

The effect of a number of surfaces.

It is obvious that in proportion to the number of reflecting surfaces in a lens, so will the number of secondary images increase, and with them the danger of a flare spot. If an ordinary rectilinear be examined in the way mentioned, there will be found to be eight images, six of which will be so faint as to be almost invisible. In a portrait lens of the Petzval type, 14 images exist. This lens is very prone to give a flare spot when a small stop is used. A certain amount of flare cannot be avoided, but the extraneous light thus admitted must not be allowed to concentrate over a small area. The quantity of flare that is present varies in different lenses, and makes itself apparent by the lack of brilliancy in the pictures produced by them. In excess it results in milky photographs lacking in contrast, but it is only in extreme cases that the defect is noticeable. Surfaces that are cemented together have so little effect that they need not be reckoned, but too large a number of open or "air" surfaces should be avoided. Thus, a single achromatic lens (figure 46a) gives a more brilliant picture than a complicated lens with numerous air spaces, such as figure 47b. (This is purely an imaginary one drawn for purposes of argument).

Effect of flare on the photograph.

Figure 46.



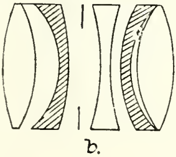


Figure 47.

The brilliancy always attributed to the old landscape lens (figure 46a), and quite rightly so, was due to this reason. Another factor which leads to flare is the presence of steep curves in lenses. The greater the angle at which the light strikes the various surfaces of a lens the larger is the proportion that will be reflected. If it is reflected outwards away from the camera it will not produce flare, it will only slightly reduce the rapidity.

Effect of steep curves on flare.

If, on the other hand, it is not reflected away from the camera but inwards, a perceptible amount of damage may result. The number of outside surfaces is worth taking notice of when purchasing a lens, especially if it is to be used for telephotography, as the telephoto attachment means the addition of at least two more reflecting surfaces, to the detriment of the image.

Flare in telephotography.

Flare spot is an unpardonable defect in a lens, while flare, if present in only small quantities, is immaterial; if it is excessive, the brilliancy of the picture is diminished.

It is worth a photographer's while to select a lens as free as possible from this defect.

The order in which lenses can be placed with regard to freedom from flare is as follows*:—

Relative freedom from flare of various types of lenses.

(1) Single achromatic.
(2) Rapid rectilinear.
(3) Double orthostigmat.†
(4) Unsymmetrical anastigmats, with numerous air spaces.

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* The above classification is only general, a badly-made single achromatic may be worse than a good rapid rectilinear.

† Might be bracketed equal to the rectilinear.

BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION III.

(1) A simple lens does not fulfil all requirements.

(2) A lens should faithfully reproduce every point of the object in the picture.

(3) To do so, it must be corrected for
- (a) Chromatic aberration.
- (b) Spherical aberration.
- (c) Astigmatism (radial and tangential).
- (d) Curvature of the focal surface.
- (e) Distortion.

(4) Chromatic aberration is caused by the inability of a lens to converge rays of white light coming from an illuminated point to a similar point in the image.

(5) A simple single lens is non-achromatic.

(6) A lens made of two glasses can be entirely achromatized for two colours, the others being almost corrected.

(7) A lens of more than two glasses can be entirely corrected for three colours, the other colours being so slightly uncorrected that the result is practically perfect.

(8) It is by combining lenses with different dispersive powers that this correction is effected.

(9) A non-achromatic lens is said to have a chemical focus.

(10) Spherical aberration is due to the use of spherical surfaces.

(11) It is the inability of a lens to convey the marginal rays to a point at the same distance from the lens as the central ones.

(12) When spherical aberration is present, a point is represented by a circle and not by a point.

(13) If this circle be more than 1-100 of an inch in diameter, the lens is badly corrected.

(14) Astigmatism is an error of the oblique rays.

(15) Where astigmatism is present the rays, instead of being brought to one focal point, are brought to two focal lines.

(16) The distance between these lines is the measure of the astigmatism.

(17) A point midway between these lines gives the position of the circles of least confusion.

(18) Lenses which are particularly free from this error are called orthostigmatic or anastigmatic.

(19) Curvature of field is the error caused by the focal plane being curved instead of flat.

(20) Distortion due to the lens causes straight lines in the object to be reproduced as curved lines in the image.

(21) There are two kinds of distortion, known as barrel and pincushion.

(22) All single lenses are subject to some degree of distortion.

(23) This error is often overcome by combining two lenses which possess the error to an equal and opposite extent.

(24) The position of the stop influences the amount and kind of the distortion.

(25) Flare is caused by the presence of extraneous light in the camera which does not take part in the image formation.

(26) Flare spot is the concentration of this light within confined limits.

(27) The greater the number of "air" surfaces the greater is the danger of flare.

(28) The presence of flare makes itself known in milkiness and lack of brilliancy in the picture.

SECTION IV.

PROPERTIES OF LENSES.

In the earlier pages of this book certain characteristics of lenses have been alluded to, but the complete discussion of their properties has been left to a separate chapter. The subject is usually considered to need for its elucidation the use of mathematical formulæ and abstruse calculations. No doubt for the scientific investigator, or for the optician, such may be the case, but a correct grasp of these properties can be obtained in a much simpler manner. After all, what interests the photographer is the actual use of his instrument, and although a knowledge of the reasons which govern its suitable employment is invaluable, this knowledge need not be extended to the degree necessary for the calculation of a new type of instrument. Each property will be considered in turn, and its influence and importance described. A full appreciation of the underlying factors governing the use of a lens will help the photographer to understand the reasons why some types of lenses are more suitable than others for particular work.

Section V., which follows this one, will briefly describe the chief types of photographic lenses, and from a careful examination of these two sections, the choice of a lens suitable for any purpose should be easily made.

The properties to be discussed are taken in the following order:—

(1) Focus.
(2) Rapidity.
(3) Depth of focus (depth of definition).
(4) Brilliancy of definition.
(5) Angle of view (and perspective).
(6) Equality of illumination.
(7) Area of critical definition.
(8) Absorption, reflection and scattering of light.

(1) Focus.

Definition.

The focal length of a lens is the measure of its refracting power and of the size of the image it will produce.

The focus or focal distance is the distance from the photographic plate to the lens, when it is so placed that a distant object is sharply depicted or focussed. As a lens is generally of considerable thickness, the particular point from which the focus should be measured becomes a matter of importance. In the early days of photography lenses were often classified by what was called their back focus, which was the distance of the back surface of the lens from the plate. This method was convenient, inasmuch as it indicated the length of the camera extension required. In the case of the early photographic lenses it was approximately accurate, but as soon as the construction became more complex it proved to be misleading, for instance, one lens having twice the back focus of another will not of necessity give an image twice the size. The point from which the focus should be measured is that point upon which the lens may be rotated or swung without moving the image on the ground glass (see Appendix II.). In single view lenses it is near the back surface of the

Position from which to measure the focus.

lens, in doublets of the rectilinear type it is close to the iris diaphragm; in most symmetrical orthostigmats it is also close to the diaphragm, and measurements from it to the ground glass are sufficiently accurate for all ordinary purposes. In non-symmetrical forms of lenses such as the Petzval portrait, telephoto, etc., the point may be very much in front or behind the diaphragm; in this case the back focus of the lens will give entirely erroneous results; for instance, when pairing lenses for stereoscopic work, two lenses might be selected having identically the same back focus, but having different equivalent foci, consequently the sizes of the two pictures would be different, rendering them useless for stereoscopic work.

Method of finding the position from which to measure the equivalent focus.

There are several methods of finding the position from which to measure the equivalent focus, but one lends itself to special consideration, as by its means such terms as equivalent focus and optical centre can be explained.

Suppose an ordinary photographic lens of the rectilinear type to be focussed so as to throw an image of some distant object, say a church tower, upon the ground glass. It is possible to select a thin spectacle lens of such a focus that it will give an image of this object of exactly the same size. The distance from the edge of this thin lens to the ground glass will be the "equivalent" focus of the rectilinear lens under examination. In fact, this explains the term "equivalent" focus, which signifies the focus of an infinitely thin lens which will give a picture equivalent in size to that produced by the photographic lens.

Optical centre.

If a mark be made on the lens mount to correspond with the edge of the spectacle lens, the position from which to measure the equivalent focus will be found. It has been the custom to call this point the optical centre of the lens, but if the lens be turned round and a second mark be made on the mount it will be found not to coincide with the one already made.

Equivalent planes.

From this it will be seen that there are two positions from which the focus must be measured, according to the way that the lens is turned, and consequently it cannot have one optical centre; it will have two "equivalent planes," the front and back.

Nodal planes.

The planes are sometimes called "nodal planes."* As a lens is almost always used one way round, there is seldom any necessity to know more than one.

Panoramic cameras.

There is a type of camera that actually makes use of the fact previously mentioned, viz., that if a lens is rotated on its back equivalent plane the picture will remain stationary. In the "panoramic" cameras the lens swings on this plane as a centre, and the image is not blurred during the movement of the lens; naturally it requires accurate adjustment to ensure success, and if a panoramic camera gives poor definition the position of the swinging centre should be tested.

Position of the object for copying full size.

In the definition of focal distance given at the beginning of this section, it was stated that the object in focus must be at a great distance. If the object is brought nearer to the lens the focal length will be gradually increased till a point is arrived at where it will be twice the true focal distance from the lens; when this is the case the object will be at an equal distance in front of the lens.†

That is to say, the object will be the same distance from the lens that the image is, and the object and its image will be of the same size.

The distances of an object from the lens and of its corresponding image are called the

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* See Appendix I. The Gauss Planes.

† As a matter of strict accuracy, the distance of the object must be measured from the front equivalent plane and the image from the back.

"conjugate foci," and they bear a definite relation to one another, the knowledge of which is of assistance to the photographer in determining focussing scales and making tables for enlargements and reductions.

Conjugate foci.

The effect of using lenses of different foci:—It may now be pointed out in what respect the focus affects the photograph. The first and most important result produced is the scale of the picture. The size of the image of an object will depend on the lens employed; a distant ship at sea photographed by a lens of one inch focus would be so small as to be practically invisible, whereas if a lens of 20-inch focus had been employed the image would have been twenty times the size. Every type of lens may be made of any required focus, and the question of the most suitable length is an important factor in its choice. The question largely depends on the size of the picture. In a small picture the principle objects must of necessity be small, thus in a ¼-plate picture a house ·1 inch high might be all that is required; whereas if it were reproduced that size on a 12 × 10 plate, it would be ludicrously small. For the ordinary run of work a general principle has been adopted, whereby a lens is selected having a focal length about one-third longer than the base of the plate on which it is to be used. Naturally the focus of a lens also determines the size of the camera requisite for its use; a 10-inch focus lens will require a camera with an extension of at least 10 inches to allow of the focussing of objects at infinity, and to allow of focussing nearer objects an extra 4 or 5 inches should always be provided. If it is to be used for copying full size, it should have an extension of at least 20 inches. It is in this connection that the importance of conjugate foci becomes apparent, for, when the object is at a great distance from the camera the focus of the

Effect of focus upon the picture.

Effect of focus on camera extension.

lens under those conditions will be its normal equivalent focus. As the object which is being photographed is brought nearer to the camera so will the conjugate focus increase, slowly at first, but rapidly as the object becomes very near. If the object approaches from infinity to 50 feet, the alteration with a 6-inch lens will be hardly perceptible; but when it is at a distance of 24 feet the increase of the conjugate focus over the equivalent will be $\frac{1}{8}$ inch, at 4 feet $\frac{3}{4}$ inch, at 2 feet $1\frac{1}{2}$ inch, and at 1 foot 6 inch.

Rule for finding the conjugate focus.

To obtain the conjugate focus of an object:— Take the distance of the object from the lens, deduct the focus of the lens and divide by the focus, divide this amount into the focus and the result will be the distance that the ground glass of the camera will have to be shifted from its normal position.

The above distance is always in a direction backwards, and that is why the rear of a focussing camera is racked backwards, or the front forwards in focussing near objects. The amount of the motion provided in the camera limits the nearness to the camera at which objects can be sharply focussed and photographed, and only a camera with a double extension can be used for copying life size, without having resource to special or supplementary lenses.

The actual amount of movement necessary varies with the focus of the lens.* The movement necessary varies as the square of the focus, that is, a 2-inch focus lens requires an alteration of only a $\frac{1}{4}$ inch to focus objects at 20 inches; while a 4-inch lens, to obtain a like result, necessitates a movement of 1 inch.†

It will occur to the photographer that, however short the focus of a lens may be, there will remain the necessity for some movement in order to focus objects at different distances from the camera, and that when a quarter-plate camera is fitted with, say a 5-inch lens, this movement must be considerable. It seems strange, therefore, that in a camera of this kind the lens can be fixed at one position, allowing of no movement either forwards or backwards, and yet produce clear pictures of objects at either 30 feet or infinity. If the rule referred to previously be employed, the total change of focus necessary for a 5-inch lens for objects between 30 feet and distance will be found to be only $\frac{1}{72}$ inch. Theoretically the picture will be out of focus for either objects at 30 feet or in the distance, but it will be to so slight a degree that it need not be considered. This point will be dealt with more fully under the heading "depth of definition," but it shows that short focus lenses have greater proportional depth than those of longer focus.

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* The longer the focus of the lens the greater the alteration necessary for objects at different distances.

† An error is introduced in the above calculation when very large variations of focus are considered, but for practical purposes the movement required varies as the square of the focus.

Fixed focus.

Fixed focus hand-camera-lenses should, therefore, be of as short a focus as is compatible with pictorial effect and covering power. Where focussing scales are provided this is not of so much importance, but fixed focus cameras have many advantages, and if they are adjusted by an optician who uses a microscope for focussing the lens, they will undoubtedly procure a finer average of definition than where the sharpness depends on rapidly judging the distance of the object and setting a pointer to a scale.

Most suitable focus.

Supplementary lenses.

Alteration of the focus by means of supplementary lenses:—This system has recently become popular on account of its convenience when used in conjunction with fixed focus cameras; it is, in fact, the only system applicable to this type. Such lenses are generally called magnifiers. They were first commercially introduced by Messrs. R. & J. Beck, Limited, in connection with their "Frena" cameras, and have through their instrumentality become widely known under this name. They may be considered as lenses for a special purpose, and will be fully discussed under Section VII.

The question of the most suitable lens and focus to choose for any specific branch of work is too large to be discussed except under the chapters dealing with particular applications of photography (see Section VI.) It will be sufficient here to indicate that the focus required for any given size camera cannot always be the same. For portraiture the lens should have a focus at least three times the length of the longest dimension of the plate. For landscapes it is desirable to have more than one focus at call. For hand cameras of the snap-shot class a fairly short focus is desirable. While for copying, process work, etc., such conditions as the position of the ruled screen, the distance of the source of illumination, etc., affect the question of the most suitable focus to be employed.

(2) DEPTH OF FOCUS OR DEFINITION.

Definition.

By depth of focus is meant the property possessed by a lens of depicting more than one plane of the object or view sharply upon the plate.

In the explanation of focus, it has been pointed out that two objects at different distances from the lens will be brought to a focus on different planes behind the lens, however slight be their separation, or, to express it otherwise, the lens will have a different focus for different planes in the view. Nevertheless, although this may be theoretically true, it is found in practice that there is a considerable range of distance within which all objects will be so sharply defined that the eye cannot discern any indistinctness.

Explanation of depth of definition.

This range of distance is called the depth of focus or definition, and is of vital importance to the photographer. The eye has limits of definition, beyond which it cannot any longer discern what is sharp and what is not. It has been assumed that a point will appear as a point in the photograph, so long as it is not a circle of more than 1-100 inch in diameter when viewed at a convenient distance of 12 inches, in other words, as long as it does not subtend an angle of more than three minutes to the eye. The reason for the limit of vision is that the retina of the eye consists of a number of rods and cones, and it is generally supposed that two points will not be recognised as such by the eye, unless their images are sufficiently separated to fall upon two rods or cones of the retina. If the two images are so close as to both fall upon one rod or cone, they will appear as one point.

Limit of vision of the eye.

There are three factors that govern depth of focus.

Factors governing depth of definition.

(1) The focus of the lens.
(2) The aperture of the lens.
(3) The presence of spherical aberration in the lens.

(1) The focus of the lens. The shorter the focus the greater the depth of definition. In relation to objects that are not too near the camera this depth varies inversely as the square of the focus, and a lens of 2-inch focus will give 4 times the depth of focus of a 4-inch lens, and 36 times that of a 12-inch lens, provided that the apertures are the same.

(2) The aperture of the lens. The smaller the aperture or the more nearly a lens approaches a pinhole, the greater becomes the depth of definition. This is what might be expected, as a pinhole has limitless depth. The question of aperture is so important that a full consideration of its bearing on differing focal lengths is desirable.

In figure 48 are represented the cones of light thrown upon the ground glass or plate by

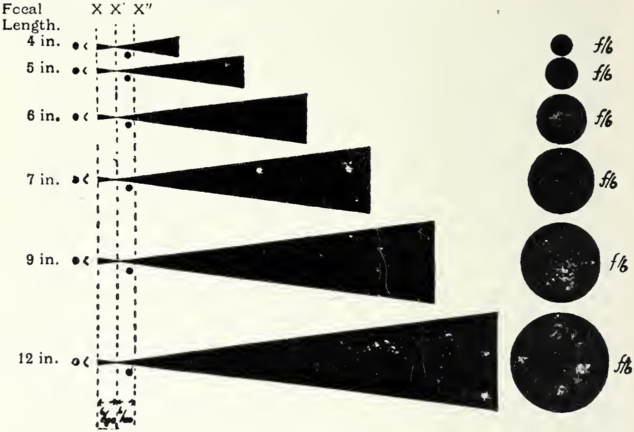


Figure 48.

X = Focal plane for objects near the camera.
X' = Focal plane for objects in the middle distance.
X" = Focal plane for objects at infinity.

lenses of the various foci illustrated, but all having the same aperture, namely, f/6 ; in consequence of this the cones of light will all be similar and embrace the same angle, namely, 9°28', and the position of the line X represents where the cones, after having become a point at the line X', separate again to the extent of 1-100 inch, the limit for sharp definition.

The foci chosen are 4 inches, 5 inches, 6 inches, 7 inches, 9 inches and 12 inches; the diagram will help to prove that the longer the focus of a lens the less will be the depth of definition. The distance of the areas of sharp definition, from X to X", is the same in all ; but this distance XX" inside the camera does not represent with different foci lenses the same range of objects outside the camera. For applying the rule given on page 88, in the case of a 12-inch lens it is only objects between 201 feet and distance, whose images lie within the space XX', while in the case of the 4-inch lens the same space will include those between 22 feet and infinity, a very marked difference. The aperture f/6 has been chosen because experience shows this to be the limit of aperture which it is convenient to use for rapid work in the field; any increase means such a loss of depth of focus that extremely careful adjustment is necessary for every plane, to obtain even approximately good definition.

Largest aperture for rapid work.

If the dotted line X″ be at the same distance from X′ as X, but in the opposite direction, it will cut the cones so as to give a circle of 1-100 inch in diameter, and if the lens be so focussed that distance objects are the most sharply defined at this point X″, and the plate be placed at X′, the depth of focus will be doubled, by making use of the *maximum* degree of diffusion permissible on both sides of the true focal plane. The distance will still be sharply defined, though the most critical definition will be somewhere between the horizon and the nearest objects.

The position of the best definition will now be—

271 inches for the 4-inch lens,
422 inches for the 5-inch lens,
606 inches for the 6-inch lens,
824 inches for the 7-inch lens,
1359 inches for the 9-inch lens,
2412 inches for the 12-inch lens,

instead of the horizon, and the nearest points in focus will be—

143 inches for the 4-inch lens,
212 inches for the 5-inch lens,
306 inches for the 6-inch lens,
416 inches for the 7-inch lens,
688 inches for the 9-inch lens,
1259 inches for the 12-inch lens.

Thus it is evident that the shorter the focus the greater the depth of definition will be, and it is possible by special care in the focussing of fixed focus cameras that considerable advantage may be gained, but it is not advisable for the amateur to attempt such an adjustment himself. A lens in a fixed focus camera, bearing a good name, should not be condemned as being incapable of giving sharp pictures until the focussing has been critically examined.

(3) The effect of the presence of spherical aberration on depth of definition :—A very small degree of spherical aberration is at times of use to the photographer, by increasing the depth of focus of the lens.

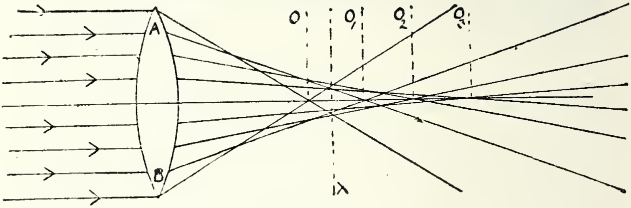


Figure 49.

To make this clear, figure 23 has been again reproduced as figure 49, and without repeating the description of spherical aberration it will be sufficient to point out that, if the screen be placed at either O, X or O′ the circles of least confusion will be approximately the same size, and if this circle be less than 1-100 inch in diameter the picture will be sharp whichever of the three positions the screen occupies, so that the actual depth of focus in this case corresponds to the distance between O and O′. Suppose, for argument, that AB be a portrait lens with an aperture of f/4, this increased depth may be of great use. If the correction for spherical aberration were perfect one plane only would be sharp, so that if the lens were used in this state for photographing a bust where the nose had been accurately focussed, the latter would be distressingly well defined, while the eyes and mouth would be fuzzy and the neck lost in mist.

Effect of spherical error in portraiture.

Of course, this could be improved by stopping down, but the value of the rapid lens would be gone. If this lens has a little spherical aberration, as in figure 49, there will be equal definition over the planes of the nose and mouth, and no part will show great lack of sharpness; the definition, of course, will not be microscopic anywhere, but the result will be better pictorially.

The better the corrections the more carefully must the focussing be done.

In hand cameras where lenses are to be used at a fixed distance from the ground glass, a small amount of spherical aberration may sometimes be allowed for the same reason, and the equality of the definition over differing planes is improved. In the beautifully corrected modern lenses this error is never present to any extent, and consequently more care is necessary in focussing. Cases have come within the writers' knowledge where a modern anastigmat has been returned to the makers as being faulty, simply because the owner did not know how to focus it to the best advantage.

Standard of definition for general work.

A circle of 1-100 inch diameter, it will be remembered, was taken as the maximum allowable for good definition when the print was viewed at a distance of 12 inches, but with this limit of sharpness the photographer must be content that his picture, which is perhaps a $\frac{1}{4}$-plate print made with a 6-inch lens, shall remain a $\frac{1}{4}$-plate print, as any enlargement will so increase the circles of confusion that the picture will become definitely blurred. When photographs are to be enlarged or critically viewed for their definition, points should not be represented by circles of more than 1-200 inch in diameter; this is the limit that Messrs. R. & J. Beck take as their standard in the "Frena" hand cameras, and the distances within which objects are sharply defined are calculated on this basis.

Standard of definition.

There are three standards of definition that the photographer is likely to hear spoken of, these are—

(1) Ideal definition.

(2) Microscopic definition.

(3) Photographic definition.

Ideal definition.

Ideal definition is the abstract idea that opticians have always before them, and the degree to which it is approached will vary in particular cases, but it can never be actually reached, for the factor of diffraction comes in with very small images, preventing the realization of this theoretical result.

Microscopic definition.

Microscopic definition is what is required for astronomical telescope object glasses and the finest microscope objectives; this term is sometimes applied to photographic lenses such as the modern orthostigmats (anastigmats), and the best of these may fairly claim to possess it.

Photographic definition.

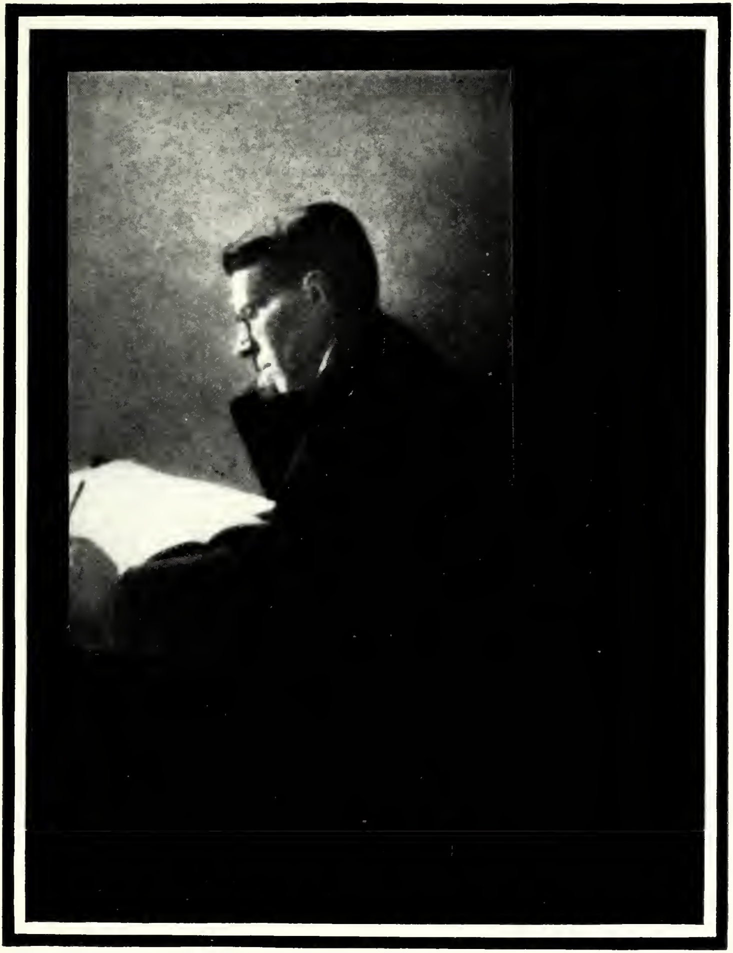
Photographic definition is of a different quality. In a photograph the objects to be sharply defined are spread out over a large area and are not confined, as in a telescope, to a single group of stars in the centre of the field. Consequently a certain something in the quality of the central definition is sacrificed to obtain a good photographic definition throughout the whole field.

To conclude this heading a table has been prepared showing the range of focus for fixed focus lenses; it shows the distance beyond which all objects will be sharp, and will help purchasers of fixed focus cameras to determine what they may expect.

See page 166.

PLATE XXI.

"STUDY LIGHT."



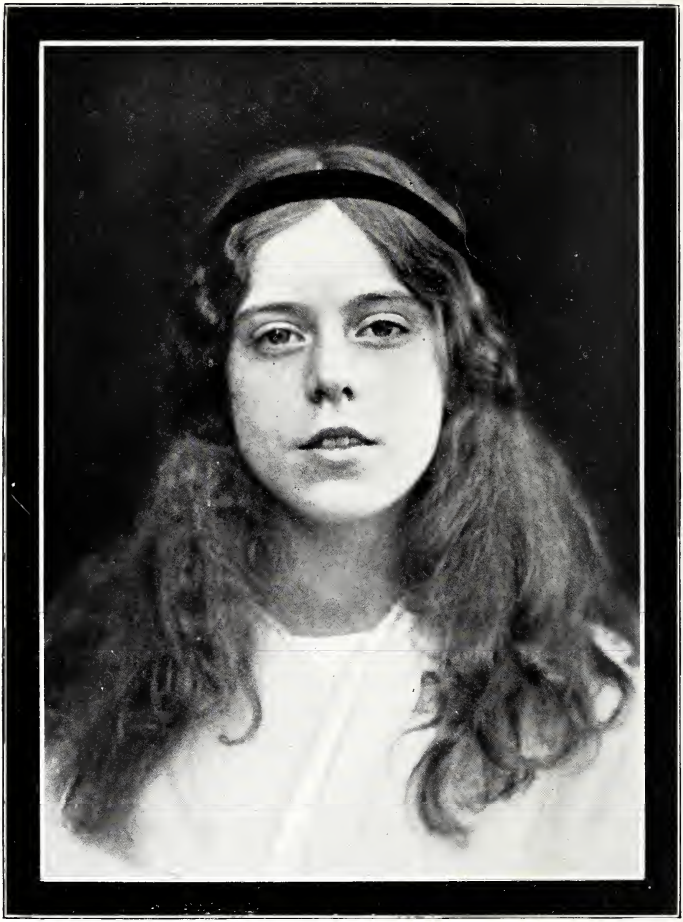
Negative by *H. Andrews.*

Taken with a 12½-inch Beck-Steinheil Orthostigmat, the ½ combination of a No. 5 Lens, at full aperture f/12·5.

See page 167.

PLATE XXII.

PORTRAIT OF A YOUNG GIRL.



Negative by *B. Bishop.*

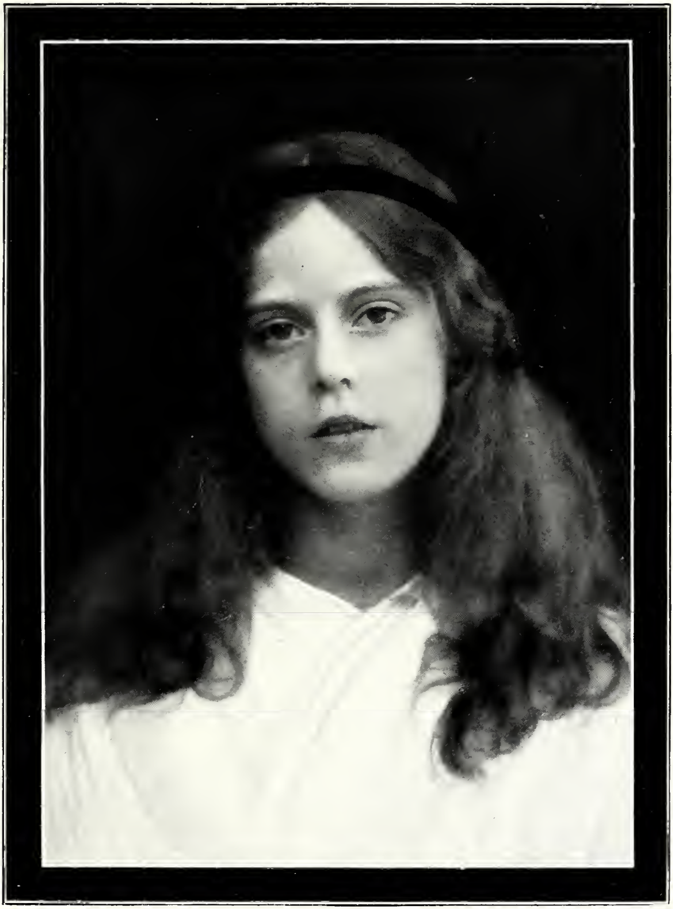
From a photograph taken with an 11-inch Biplanat at f/8, to show slight distortion due to shortness of focus.

PHOTOGRAPHIC LENSES.

See page 167.

PLATE XXIII.

PORTRAIT OF A YOUNG GIRL.



Negative by *B. Bishop.*

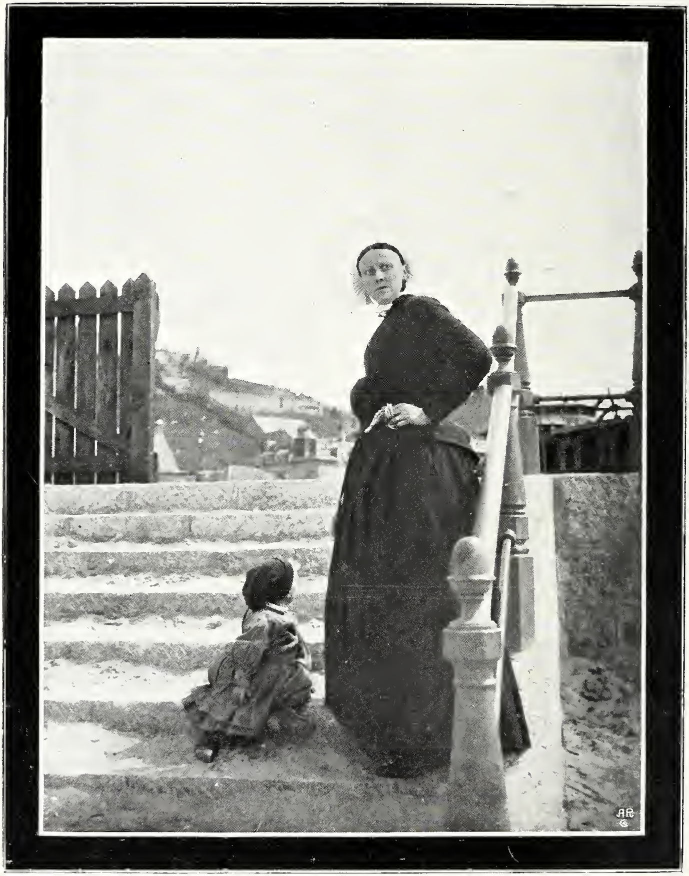
From a photograph taken with a ½ combination of an 11-inch Biplanat at f/8 (focus 20 inches).

PHOTOGRAPHIC LENSES.

See page 175.

PLATE XXIV.

A SEASHORE MADONNA.



Negative by *C. Beck.*

From a 5 × 4 Frenagraph, Beck-Autograph lens, 6½-inch focus, in conjunction with a Frena magnifier.

PHOTOGRAPHIC LENSES

TABLE OF DEPTH OF FOCUS.

Table of depth of focus.

Focus of Lens in inches.	Ratios marked on Stops.													
	f/7	f/8	f/9	f/10	f/11	f/12	f/13	f/14	f/15	f/16	f/17	f/18	f/19	f/20
	Number of feet after which all is in focus.													
4	19	17	15	14	13	12	11	10	9	9	8	8	7	7
4¼	21	19	17	15	14	12	11	11	10	10	9	9	8	7
4½	25	22	19	17	16	15	13	13	12	11	10	10	9	9
4¾	27	23	21	19	18	16	15	14	13	12	12	11	10	10
5	30	27	24	21	19	18	17	15	14	14	13	12	11	10
5¼	33	29	25	23	21	20	18	17	16	15	14	13	13	12
5½	37	31	29	26	23	22	20	19	17	16	15	15	14	13
5¾	39	34	31	28	26	24	22	20	18	18	17	16	15	14
6	43	38	33	31	28	26	24	22	21	20	18	17	16	15
6¼	47	41	37	33	30	28	26	24	22	20	20	19	18	17
6½	50	45	40	36	33	29	28	26	24	23	21	20	19	18
6¾	55	48	43	39	36	32	30	28	25	24	22	22	21	20
7	58	52	45	42	38	35	31	30	28	26	25	23	22	21

(3) RAPIDITY.

A lens in contradistinction to a pinhole possesses the property termed "rapidity."

This is due to its power of converging a large number of rays, emerging from a luminous point in the object, to a corresponding point in the image.

Measure of rapidity.

The measure of the rapidity of a lens is dependent on the size of this bundle of rays, and is directly proportionate to its aperture or effective diameter. In other words, the greater the angle included in this cone of light the greater the rapidity.*

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* To illustrate this point, suppose that in figure 50 there are two lenses A and B, both having a focus of 3 inch, but the one an aperture or diameter of only 1 inch and the other of 3 inches. It will be seen at once that the lens with the smaller aperture converges a much smaller cone of light to a focus at O, in fact, the angle of the two cones are 18°30' and 60° respectively: consequently the lens converging the large cone is the more rapid, for the area of the aperture of the lens B is nine times that of A, and it follows that it is nine times as rapid, or it might be said that B admits nine times the number of rays that A does.

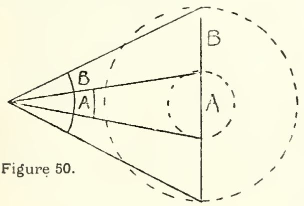

Figure 50.

Factors governing rapidity.

The rapidity of a photographic lens is not dependent solely on the diameter of its aperture, but on its diameter in relation to its focal length.

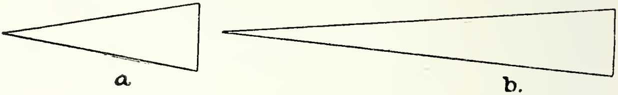

Figure 51.

In figure 51 are represented two lenses having the same apertures, both 1 inch in diameter, but of two different foci ; the first (a), is 3-inch focus, the second (b), 6-inch focus. Lens a has four times the rapidity of b, and as the aperture will divide three times into the focus it would be written as f/3 in photographic nomenclature, whereas that of b would be written f/6.

A practical example may be given. Suppose the lens a is placed in a camera and a square window is focussed upon the ground glass so that it is represented by a bright square 1 inch across, having marked the square upon the ground glass, and upon changing this lens, replacing it by the 6-inch one, the window will now be found to occupy a square 2 inches across, for the lens producing it has twice the focus and will give twice as large a picture of a distant object. Now the same amount of light from the window enters both lenses, each of which has an aperture of 1 inch, but in the case of the 6-inch it is distributed over four times the area, and each point will only receive one-quarter the amount of light. The 6-inch lens is, therefore, only a quarter as rapid as the lens with half its focus. In this example it is taken for granted that the window is at a considerable distance from the lenses.*

---

* If this interesting question is to be accurately studied, attention should be confined to the angle of the incident cone of rays. Suppose a sheet of brown paper be placed over the window, and a hole an inch square be cut in it, and the two lenses mentioned above be taken and placed in such a position and at such a distance that the images of the hole are in both cases an inch square, it might be supposed that the lenses in this case had the same rapidity, since the light is spread over the same area. Reference to figure 52 will, however, show the fallacy of this reasoning.

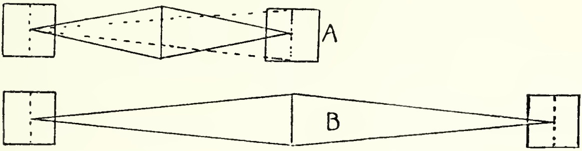

Figure 52.

In order that the two images formed by A and B may be the same size, the shorter focus lens must be brought closer to the brown paper, and it will then collect a larger cone of rays owing to its proximity to the object. The cone of rays in figure 52 collected by B is much smaller in angular measurement than that collected by A, because of its greater distance from the object; indeed, the cone is but a quarter the volume, and it follows that the rapidity is a quarter of A as before, this is equally true of objects at intermediate distances. It is not till the object is at a considerable distance that the previously cited example is accurate.

Another interesting point connected with this subject is introduced in astronomical photography. When photographing stars, etc., the only consideration is the actual diameter of the lens, the focus having no influence on its rapidity. For the image of a star has no size, it is so far off that, however long a focus lens be employed, its image will still only be a point, so that it resolves itself into merely a question of the lens that can collect the most light. Figure 53 will illustrate this point, let A be a lens of, say, 1-inch aperture and 2-inch focus; B a lens of 12-inch aperture and 60-inch focus, and X the star under consideration, it is clear that the two images at A and B will be exactly the same size, and so it remains only to discover which lens admits the most light. The star X is emitting rays in every direction, so that a lens 12 inch in diameter must receive and transmit a greater number than one only 1 inch in diameter; the rapidity of B in this case is greater than A in direct proportion to its aperture. At the same time the two apertures of A and B would be written f/2 and f/5, when used for ordinary photographic purposes A would then be more rapid than B. The foregoing explains why, for astronomical object glasses, a large diameter is essential, while length of focus is not of such great importance; indeed, most telescope object glasses, have apertures varying between f/12 and f/16.

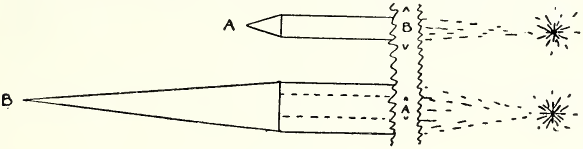

Figure 53.

Expression of rapidity.

R.P.S. Standard.

Having reached the conclusion that the rapidity of a lens, neglecting the question of absorption by the glass itself, depends upon the aperture or effective diameter of the lens and upon the focus, the question as to how this "rapidity" can be expressed calls for attention. For many years the method of describing this property was the subject of much discussion and it was not till the Royal Photographic Society took the matter up that the present nomenclature was adopted. It is adhered to by the lens manufacturers in this country, and is generally used for lenses prepared for the English market. It is evident that no system of expressing rapidity can be usefully employed that does not combine the aperture of the lens in relation to its focal length. The obvious method is to say that a lens has an aperture of $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{8}$, etc., of its focus. Its rapidity may therefore be expressed as f/3, f/4, f/8, etc. Two lenses, each of which has an aperture of say f/8, will have an equal rapidity whatever their foci may be and the exposure required to get a given result will be the same in both cases. The question that had then to be decided, was the most convenient sizes for the diaphragms, and it was thought desirable that each stop or diaphragm should admit half the light of the preceding one. The following series of apertures were fixed upon to fulfil this condition:

Table of apertures.

Aperture.	f/4	f/5·6	f/8	f/11·3	f/16	f/22	f/32	f/45	f/64
Relative exposure necessary.	1	2	4	8	16	32	64	128	256

The starting point is considered to be f/4, in which case the aperture is a quarter of the focus, and it is only in special cases that a lens having a larger aperture than this will come into the hands of the photographer. It will be noticed in the above list that f/4 is four times as rapid as f/8, because this expression is the measure of the diameter of the aperture, and a circle which is double the diameter of another has four times the area and admits four times the light. It might be supposed that a measurement of the diaphragm of the lens divided into the focus would give the actual rapidity; this is quite true of a lens like the single achromatic, which has the diaphragm in front. The diaphragm is, under these circumstances, the correct measure of the bundle of rays which strike the lens and pass on to the plate to form the image. On the other hand, where the diaphragm is placed between or behind any of the component lenses, the measure of the diaphragm does not express the size of the incident bundle of rays forming the image, for the light, on passing through the front combination, has been slightly converged before it reaches the diaphragm of the system.

Influence of the diaphragm upon the measure of the rapidity.

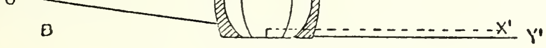

Figure 54.

Figure 54 illustrates two lenses, A and B; the one A, a single lens and the other, B, a doublet have similar sizes of diaphragm, but in the case of A the diaphragm is in front while in B it is between the combinations. In the first case the light entering is restricted solely by the diaphragm, whose diameter is an accurate measurement of the incident bundle of rays. In the case of B, the diameter of the stop, although the same as that of A, instead of allowing only those rays indicated by the dotted lines XX′ to pass, includes the larger bundle YY′, which are coned down by their refraction through the front lens; it follows that the lens B is the more rapid although the diaphragm measures are the same. In this case the diameter of the bundle of rays YY′ allowed to pass into the camera is the effective aperture of the lens, and it is the focus divided by this quantity which enables a comparison to be made between lenses of varying foci, and is the true measure of the rapidity.

An 8-inch focus lens having an effective aperture of 1 inch will have a rapidity expressed by f/8, in the same way a 16-inch focus lens with an effective aperture of 2 inches will also have a rapidity of f/8, and therefore, require the same exposure as the 8-inch. If in either of the above cases the diameter of the diaphragm instead of the effective aperture had been 1 inch, the lenses would have had greater rapidities, probably about f/7 instead of f/8. It is only within recent years that there has been any conformity among lens makers in numbering the various lens apertures, and even to-day there is a chance of the photographer being puzzled by unusual methods of nomenclature, but the following rule may assist the possessor of an abnormal lens in gauging its rapidity.

Nomenclature of apertures by different makers.

If a lens be marked f/13, or some other unusual aperture, square the denominator, i.e., 169, and this number compared with the square of some well-known diaphragm denominator, say f/8, 8 squared is 64, will give the relative exposure required; the f/13 lens would want 169/64 times the exposure of the f/8 lens, or nearly three times. As another example,

Rule for comparing the rapidity of lenses with different numbers.

if the relative quantity of light admitted by a lens marked f/4 and one marked f/11·3 is required, square 4, it equals 16, and 11·3 squared equals 128, 16 goes 8 times into 128 and, therefore, the first lens admits 16 times the light of the second and is 16 times as fast.

Naturally a lens that is twice as fast as another can be successfully used under conditions of bad light, where the other would be useless, and rapidity is often a prime factor in governing the choice of a lens. In the table given on page 100, a second line of figures is shown indicating the relative exposure necessary to produce identical results with different stops. This series of numbers is sometimes used either in place of the other ones or in addition; it is called the universal system, or the U. S. numbers (not the United States numbers). It is seldom employed except in conjunction with the first method, when it is useful for checking the exposures. The original method for altering all the diaphragm apertures was to place stops in front of the lens, whether a doublet or single, but this was soon found in the case of the doublet to be injurious to the illuminating power of the instrument at the edge of the field. The correct position was found to be between the lenses, where a small aperture affected all parts of the picture in the same manner. In the early days the aperture was altered by unscrewing the lenses and dropping a metal or cardboard stop between them.

Methods of altering the aperture of a lens.

Colonel Waterhouse simplified this by arranging stops to slip into a slot in the lens mount, these stops are known as "Waterhouse" or "drop" stops. With each lens a number were supplied, and the changes in aperture were limited to the number of the stops. Intermediate sizes were impossible, except by pasting black paper over the stop and making a fresh hole, which was unsatis-

Waterhouse system.

Disadvantages of the system.

factory, and it was evident some other form of diaphragm was required.

By the iris diaphragm.

The iris diaphragm was first introduced about the year 1885 by Messrs. Beck and Messrs. Lancaster, and has been subsequently adopted by all lens makers. Although it is sometimes not an exact circle, it is sufficiently near for all practical purposes, and this method of altering the aperture, in addition to its great convenience, allows of the use of any intermediate size that may take the photographer's fancy. It has been mentioned that the system of numbering lens apertures is not yet uniform in the Continental market, and the table below has been arranged as a rough guide to those who possess a lens not numbered on the R.P.S. system. The table will enable them to translate the numbers on their lens mount into the R.P.S. standard.

Comparative table of diaphragm numbers.

COMPARATIVE TABLE OF DIAPHRAGM NUMBERS.

f/ R.P.S. System.	U.S. System.	Zeiss System.	Goerz System.	Voigtlander.	Dallmeyer System.
Beck and Beck-Steinheil lenses.	Beck and other English makers.	Zeiss new lenses.	All Goerz lenses.	Collinear.	Dallmeyer old lenses.
f/4	1	-	-	-	-
f/4·5	-	128	-	-	-
f/5·6	2	-	3	2	-
f/6·3	-	64	4	2½	4
f/7·7	-	-	6	4	5
f/8	4	-	-	-	-
f/9	-	32	9	-	-
f/10	-	-	-	-	10
f/11	8	-	12	8	-
f/12·5	-	16	-	-	15
f/16	16	-	24	16	-
f/22	32	-	48	-	-
f/25	-	4	-	-	-
f/32	64	-	96	64	100
f/45	128	-	192	-	200
f/50	-	1	-	-	250
f/64	256	-	-	256	-

Variation in individual apertures.

It can hardly be expected that each individual aperture of every lens should be tested by the maker, as this would mean an immense expenditure of time altogether disproportionate to the value. In the case of a lens of the modern orthostigmatic or anastigmatic type, where all the curves are made with the greatest accuracy, the foci of the finished lenses of one size will not vary, at the most, by more than $\frac{1}{8}$ inch, so that once a series of diaphragm apertures are found to be correct for one lens they will be accurate for all. Errors are sometimes met with in cheap lenses made by machinery, where the foci may vary as much as $\frac{1}{6}$ of the focal length, consequently the apertures which are calculated for the average may be incorrect to this extent in individual cases.

Variation of apertures in cheap lenses.

Rapidity to choose for different work.

The most suitable rapidity to choose is a question that cannot always be answered off hand. In general terms, lenses with apertures larger than f/6 are called extra rapid lenses, those between f/6 and f/8 rapid lenses, and those with smaller apertures than f/11 slow lenses.

Portrait lenses, with their very large apertures, are a class by themselves, and are of little use except for their particular branch of work. A great deal of the best work nowadays is being done with lenses that are not truly portrait lenses in the usual acceptation of the word, but are anastigmatic or aplanatic in form. The modern orthostigmat approaches the portrait lens in point of rapidity without its peculiar limitations; it can be used successfully for portraiture under fair conditions of light, and has an aperture in the neighbourhood of f/6. Where cost is of little importance it is always advisable to have a lens for landscape, architecture, instantaneous or telephoto photography with an aperture of f/6, or thereabouts, as, when such great rapidity is not required the diaphragm can be used, and when they are stopped down these anastigmats are equal, or superior, to any other type with the possible exception of extremely wide-angle lenses.

Increased rapidity means decreased depth of definition and it is best to employ the smallest aperture on the lens that the condition of the light will permit. If a snap-shot can be successfully taken at 1-20th of a second it is better to use this speed and an aperture of f/16 than to open the lens to f/8 and give 1-80th of a second. This subject will be more fully treated of under a subsequent heading.

BRILLIANCY OF DEFINITION.

Definition.

Brilliancy of definition is the power possessed by a lens of rendering the blacks in the object as blacks in the image, and the whites, white. In a lens possessing this property to a marked degree there will be no levelling down of the contrasts, the white will not be grey or slightly fogged, and the blacks will be jet black.

Tones in photography.

Photography is essentially a means of reproducing in monochrome a variety of coloured objects with different luminosities; its success pictorially depends on the gradation of the tints, and the greater the variation of the tints, the more successful and convincing the result. Every successive step between a pure white and an intense black should be attained in order to differentiate between the innumerable degrees of brightness in nature. It is important to distinguish between the lowering in tone produced by the lens, and the similar effect due to a misty atmosphere or to incorrect exposure or development. By far the majority of flat negatives are due to these latter causes, but there are cases where the lens is to blame.

The factors that govern the property of brilliant definition are—

Reflecting surfaces.

Air surfaces.

(1) The number of reflecting surfaces in the system. In the section on corrections it was indicated that, to get a brilliant image, there must be no internal flare or scattering of light within the camera. If there are a large number of "air" surfaces, there is more chance of the brilliancy of the result being affected. Cemented surfaces have no appreciable effect. A single achromatic lens (a spectacle lens is not considered) gives, if of good quality, the most brilliant images (this term brilliancy must not be confounded with critical definition), and a glance at the diagrams of the various types of lenses (figures 55-59) will show why this lens stands highest on the scale. It should not be forgotten that this lens, unless carefully designed, may suffer from a serious flare spot (figure 44, page 78).

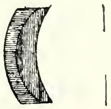

Figure 55.

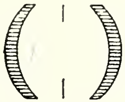

Figure 56.

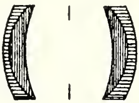

Figure 57.

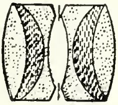

Figure 58.

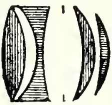

Figure 59.

Effect of bad mounting.

(2) Mechanical defects. The quality of the polish of the lens surfaces, explained later when discussing "scattering" (see the conclusion of this section), if it be bad, throws a good deal of useless light into the camera. Mechanical defects may be due to bad mounting, so that light is reflected on to the plate by unblackened screw threads or other parts of the mount, to the detriment of

the image. The interest attaching to the property of brilliant definition in various lenses is one that is of only secondary importance. The greater the brilliancy of definition the greater the value of the lens to the photographer, and a lens with the least number of open surfaces is the best in this respect, but the better lenses by all makers of repute, provided they have not more than four outside surfaces, leave little to be desired. No one would continue to use a single lens in place of an orthostigmat simply because the latter gave slightly less theoretical brilliancy. Its other advantages far outweigh this hypothetical disadvantage.

Milkiness due to many surfaces.

Indeed, it is often impossible to see the difference between the performance of a lens with two reflecting surfaces and one with four, but with one having 6, 8 or 10 a difference becomes apparent. There is one connection where this question becomes of premier importance, and that is in choosing a lens to use with a telephoto attachment. In this case the negative lens in itself has two, or perhaps four, reflecting surfaces, and if the positive has more than four the results may tend towards milkiness. It is difficult, without the use of a screen and orthochromatic plates, to get rid of the atmospheric "blue haze" in pictures of distant views, and all avoidable errors which tend to augment this effect should be got rid of.

AREA OF CRITICAL DEFINITION.

Definition.

Explanation of the area of critical definition.

By area of critical definition is meant the area of that portion of the image which is critically sharp. It has no reference to the size of the field, as the lens may give a large picture, the central portion only of which is well defined. The area of the circle of critical definition is measured by the diameter of that circle of the picture on the photographic plate, which shows no sign, with a moderate magnification, of any blurring of the image produced by such defects as spherical aberration, curvature of field, astigmatism, etc. Points of light should be represented by dots smaller than 1-100 inch in diameter to be considered as being rendered critically.

Standard of critical definition.

The standard taken will be about 1-200 inch. A lens that may cover the whole of a ½-plate sufficiently sharply for ordinary contact prints may have a much smaller area of critical definition. On the other hand, there are lenses that will render points of light as circles very much smaller than the standard, but the photographic plate would not possess a fine enough emulsion to differentiate between such delicate details except in telephoto work, where the image is optically magnified.

Factors governing the area of critical definition :—

(1) The optical construction of the lens.
(2) The position and size of the stop.
(3) The length of focus of the lens in use.

Optical factors.

Achromatism, spherical aberration, astigmatism and curvature of field must be accurately corrected to secure the finest results. The lenses must be properly mounted so that there shall be no error introduced by bad centring or incorrect separation of the combinations, and the actual holding of the individual lenses in their cells, so that no strain is put upon them, is a *sine qua non.* There will be no critical definition unless these errors are attended to, and the degree to which they are eliminated will govern the size of the area of critical definition. In the finest lenses these errors are so completely corrected that the definition* will not fall off over the whole surface of the plate.

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* When speaking of the definition that a lens will give, it is always in relation to the image of objects lying in the same plane, and not in different planes. The photographer must not test his lens for critical definition at full aperture on a street scene, but upon a hoarding or level surface. It may not be so pictorially attractive, but its practical value as a test is higher.

Plates XI., XII. and XIII. are reproductions of photographs of a test chart taken with three representative types of lenses at full aperture, showing the difference in the size of the area of critical definition. The examples are all taken with lenses of approximately the same focus. In order to cover the whole of any standard size plate, the following areas of critical definition are necessary.

TABLE OF AREAS OF CRITICAL DEFINITION.

Table of areas of critical definition.

Plate.	Area of Critical Definition.	Length of Focus of the Lens required to cover them.		
		Single View f/16.	Rapid Rectilinear f/11.	Orthostigmat f/6·3.
3½ × 3½	4¼	5 in.	4¾ in.	3½ in.
4¼ × 3¼	5½	6½ ,,	5½ ,,	4⅜ ,,
5 × 4	6½	8 ,,	7 ,,	4¾ ,,
6½ × 4¾	8	10 ,,	8¾ ,,	6 ,,
7 × 5	8¾	12 ,,	9½ ,,	6½ ,,
8¼ × 6½	10¾	16 ,,	12 ,,	8½ ,,
10 × 8	12¾	19 ,,	14 ,,	10 ,,
12 × 10	15½	22 ,,	18 ,,	11 ,,

Relative perfection of lenses in this respect.

It will be noticed that the rapid rectilinear and single view lenses are decidedly inferior in their corrections to the orthostigmats (anastigmats), and the above table fairly represents their qualities so far as those of shorter focus are concerned—but it is somewhat too favourable to the rapid rectilinear and single view for foci longer than 9 inches. Inferior correction is more readily noticeable in long than in short focus lenses. To obtain really critical definition over large plates with single view and rapid rectilinear lenses necessitates the use of small stops.

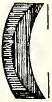
Position of the diaphragm.

(2) The position and size of the stop or diaphragm :—The determination of the correct position for the stop in a single view lens is in the first instance decided by the optician, but the photographer can sometimes make a decided improvement in a cheap lens by a slight alteration of the position of the diaphragm. In the case of a doublet or triplet the amount of possible movement is restricted by the separation of the two combinations of the system between which the iris is placed, and it cannot, therefore, materially influence the result.

Influence of the position of the stop.

The accepted method of mounting the single view lens (the greater number of which are meniscus in form) is with the stop or iris diaphragm at a distance of about 1-5 of the focal length from the concave surface of the lens (figure 61), this being the position at which the good definition, flatness of field and angle of view are at their maximum. If one quality is in excess, it is at the expense of the others, thus if the diaphragm is moved towards the lens (figure 60) from the best position the angle of view increases rapidly, the field becomes more and more curved, and the area of critical definition is rapidly restricted. A very large plate may by this means be illuminated, but the area of perfect definition is small.

Figure 60.



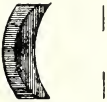


Figure 61.

Illustration of influence of position of stop.

To illustrate this point plates XIV. and XV. have been prepared, the first is taken with a single lens of 8½-inch focus, with the diaphragm f/12·5 close to the lens, and the second with the diaphragm at the same aperture but at a distance of 2 inches from the same lens.

The area of critical definition in the one case is represented by a circle not more than 3 inches in diameter, while the latter is as much as 6 inches. This great difference is obtained by merely altering the position of the stop. The size of the stop materially affects the area of critical definition. The smaller the stop the larger the area. This is true within limits, but should the aperture be so reduced that diffraction (see page 14) sets in, the definition will be reduced. It also largely depends on the nature of the lens, as certain errors are more readily cured than others by a reduced aperture. It has usually been assumed that a stop smaller than f/72, that is 1-72 of the focus, should not be used on this account. In short focus lenses this is probably true, but practical experience does not bear this out in the use of lenses of very long focus. See the section on special lenses (telephotography).

Influence of size of stop on diffraction.

(3) Length of focus of the lens in use:—It may seem almost unnecessary to point out that the area of critical definition increases with the length of focus of the lens. A glance at any maker's catalogue will show that to take photographs on a large plate a long focus lens is required. This increase is not proportional to the increase in focus, particularly with lenses other than the high-class modern orthostigmats (anastigmats), as it is impossible to make an R.R. of 20-inch focus that will give at full aperture the same relative definition as a 9-inch or a 5-inch.

Length of focus increases area of critical definition.

Plates XVII. and XVIII. indicate this, they are reproductions from the centre of the field of a 20-inch and a 7-inch R.R., and explain what is meant better than words can do.

The effect of the area of critical definition:—The careful photographer will not be long in discovering the extent of this area in his lens with its various apertures, particularly if it is a small quantity; for when using the open aperture there will be a falling off more or less marked at the corners of the plate; and to what extent it will injure his work will depend on circumstances. Portraiture or genre studies usually require that the object, or objects, of interest should be in or near the centre of the field, and the corners being blurred may be of little consequence and may even be helpful in that it will throw up the points of interest in the picture, but should the work be architectural or purely landscape the error will not be permissible. If the lens is by a reputable maker all that can be done is to use a smaller aperture, when the area of good definition may be increased to any reasonable extent.

Critical definition and portraiture.

In plates XIV. and XV. examples were given of results obtained with a single lens. The diaphragm being in different positions the same result could have been obtained by stopping down the lens. Plate XVI. indicates this and illustrates the method of improving the area of critical definition. Naturally in this latter case some rapidity has been sacrificed, but by this means a larger area can be obtained than by the first method.

Effect of incorrect separation.

An orthostigmat (anastigmat) may be reasonably expected to cover at full aperture, the plate for which it is catalogued, and if this is not the case the lens has been incorrectly adjusted. If the lens is one of short focus, mounted in a shutter of the "between the lens" type, the separation of the combinations may have been unduly increased to allow of the necessary room for the shutter-plates and diaphragm. When a lens is to be used in a camera possessing a cross and rising front, its area of critical definition should be larger. The size of this circle depends on the focus as well as upon its quality from an optical point of view, and it is quite possible to select a rapid rectilinear or single view lens that has an area of critical definition, as large as that of an orthostigmat

Example of area critical definition.

(anastigmat) of shorter focus. Thus an $8\frac{3}{4}$-inch Autograph Rapid Rectilinear will have as large a circle at f/8 as a $4\frac{3}{4}$-inch Beck-Steinheil Orthostigmat at f/6·3; an increased circle can, therefore, be obtained either by procuring a better lens or one of a longer focus of the less expensive type.*

Equality of illumination.

EQUALITY OF ILLUMINATION.

Perfect illumination.

By equality of illumination is meant the power of a lens to throw as much light to the edge of the field as to the centre:—If a lens illuminates the edges of the field as brilliantly as the centre, the equality of illumination will be perfect; but if the light gradually fades away from near the centre to the edge, the reverse is the case. There is no lens which gives perfect equality of illumination over the whole field of view at full aperture, but there are many sufficiently good to produce no appreciable difference in the photograph. When the defect is pronounced, a partially vignetted picture, bright in the centre and shading off towards the edge, is the result.

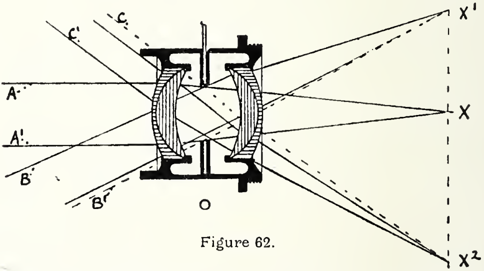


Figure 62.

Figure 63 represents a lens of the rectilinear type having a stop O placed in the centre. A bundle of rays AA′, parallel to the axis of the

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* No reference is made in this connection to the fact that using a longer focus lens means less depth of definition which, under certain circumstances, might be of more importance than the increased circle of critical definition. This has been fully discussed previously.

Cause of inequality of illumination.

lens coming from a distant luminous source, will pass entirely through the lens and will be brought to a focus at X. The intensity of this point of light at X will be directly measured by the effective aperture of the lens. Another bundle of rays not parallel to the axis will form the image of an object at the side of the picture: these rays will also pass into the lens, but a certain small part only will emerge, all those between B′ and the dotted line being unable to take part in the formation of the image at X′. Consequently the image point at X′ will not be so bright as that at X; it will take longer to impress the image of an object at the edge of the field upon the photographic plate---the difference being directly proportionate to the volume of the cone of light taking part in the formation of the two images. If the still more oblique rays CC′ are examined, the defect will be still more apparent, until a point is reached where the rays are so oblique that none can pass the lens. There must be some position in the field of every lens where the illumination begins to fall off, but in those of the best make this is near the extreme edge of the field of view. Naturally it would be preferable to have the field both bounded by a clear cut line, and fully illuminated up to this point, for it would then be possible to use the full circle if desired.

The degree of this error is measured by the proportion borne by the shaded-off part to the

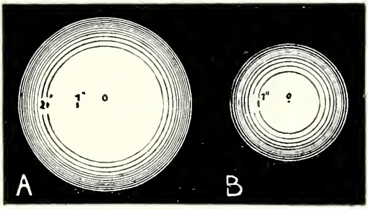


Figure 63.

Comparison of equality of illumination in different lenses.

remainder. In figure 63, A represents the circle of illumination of a lens, and is 6 inches in diameter, while B is that of a lens of the same focus giving a field 4 inches in diameter. In both cases the shading off begins 1 inch from the edge of the field, but for this reason it is not fair to say that the lens A has the same equality of illumination as B, or that, from the point of view of equality of illumination, the two lenses are equal. Lens A badly illuminates only one-third of the total field while B badly illuminates half, therefore A is some 17 per cent. better than B in this respect.

Factors governing the question.

(1) The distance apart of the constituent lenses.
(2) The diameter of the lenses.
(3) The size of the diaphragm.

In the case of the single view lens a proper adjustment of the stop enables a perfect equality of illumination to be obtained, but in other lenses the position of the diaphragm is settled by other considerations, and equality of illumination must be arrived at by the size of the lenses in relation to the aperture of the diaphragm.

The larger the component lenses in relation to the aperture, or the smaller the stop with the same lens, the more perfect the equality of illumination.

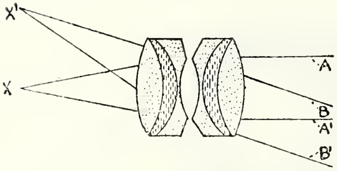


Figure 64.

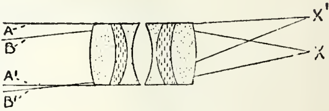


Figure 65.

To explain this point, let figure 64 represent a lens of the orthostigmatic type with full-sized combinations, and let figure 65 be the same lens with same diameter of effective aperture, but with the combinations reduced in size. Let AA′ be the central and BB′ the most oblique bundle of rays in each case, that will completely pass through, and X and X′ the positions on the focal plane of their respective focal points. It is quite clear without further explanation that the first lens gives much the better equality of illumination. This also indicates an interesting point—a lens should not be used with a shutter too small to properly accommodate it, or it will not be used to its best advantage.

The larger the lens in relation to the stop the better the illumination.

Figure 66 will illustrate why stopping down improves the equality. In II. (figure 66) the aperture is evidently much smaller than in I., and if the same reasoning is applied as in the previous case (figure 65) it will follow that the illumination is better.

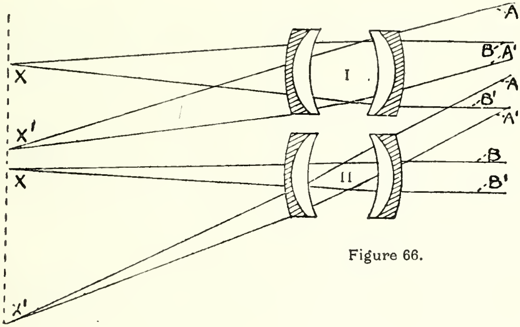


Figure 66.

Stopping down improves the equality of illumination.

Angle of the system :—The greater the angle of view included by the lens system, the larger must be the lenses if the equality of the illumination is not to be impaired.

In figure 67 a lens is represented having the power of including an unusually large angle of light without any being stopped by the mounting or margins of the lenses. Suppose the lens

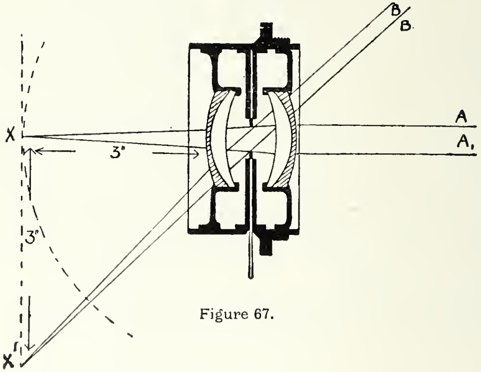


Figure 67.

Effect of wide angle.

to be 3 inches equivalent focus, then the central pencil AA'X will come to a focus 3 inches from the diaphragm, while the pencil BB', falling 3 inches away from the axis, will be over 4 inches long: consequently the images of the two equally luminous points are represented at X and X' by two points of different actinic value, so that if the exposure be correct for X it will be insufficient for X'.

The reason for this is well known: the intensity of light coming from a point or luminous source decreases as the square of the distance. An extreme case has been taken as an illustration, as it is only in exceptionally wide-angle lenses that it is apparent. If a curved plate, as illustrated by the dotted line, had been used the illumination would have been perfect.

Effect of bad mounting.

Effect of equality of illumination:—The unsuitable mounting of a lens may destroy, or rather reduce the quality of the marginal illumination. The marginal illumination will suffer unless the entire cone of rays be allowed to pass to the plate. A carelessly designed hood (figure 68, A) or a badly designed lens cell (B) has the same effect. A shutter, also, which opens and closes from the centre can only be placed next the diaphragm without ruining the illumination for a similar reason.

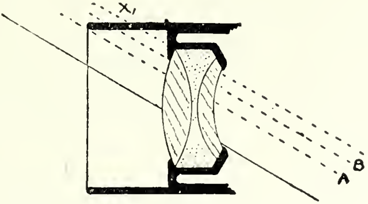


Figure 68.

Effect of prolonged exposure.

If a lens is listed to cover a given plate it is generally understood to mean that the equality of the illumination will be perfect over that plate as well as the definition. When the defect exists it can be improved by giving a full exposure, slightly longer than is apparently required; for, if the centre is only just sufficiently exposed to gather density with prolonged development, the less exposed margins will be under-exposed. If, on the other hand, the edges are correctly exposed the centre will be slightly over-exposed, but as most plates give considerable latitude for over-exposure, a good negative will result. If the area of equal illumination is as large as the plate it will suffice; though a larger area is convenient to allow of the use of the rising or cross front.

Relative merits of different types of lenses.

The portrait lens is the worst offender in the above respect, which is one of the reasons why it is being superseded by the rapid orthostigmats for group work. Stopping down is rarely of much use with portrait lenses, as it often induces flare spot. A large-aperture rapid rectilinear form of lens, such as the Biplanats (f/5·8), will, when stopped down, have a very much larger field of equal illumination than an f/8 rapid rectilinear, for its combinations are of necessity large and are fairly close together (see figures 64 and 65). The orthostigmats (anastigmats) are the nearest to perfection in this respect, and there is little reason to suppose that they will be materially improved in the near future. Aperture for aperture, an orthostigmat will have an area of perfect illumination of almost double a rapid rectilinear.

Method of equalizing the illumination.

A method of equalizing the illumination of lenses of very wide angles, say 120° and over, has been suggested, in which a star-shaped diaphragm is placed over the front lens. This cuts off more of the central light than the oblique, but is a method of hardly sufficient utility to commend itself to the practical man.

ANGLE OF VIEW.

Definition.

By angle of view is meant the amount of view which a lens is capable of including within its circle of illumination. Suppose a camera is erected opposite a row of houses, a lens with a large angle of view might include 10 or 12 of these in the picture, while a narrow angle lens might only take in 2 or 3. It must be understood that a lens called a wide-angle lens is so made, that, although it is capable of including a wide angle in the field of illumination, it will only do so if used on a large enough plate, as compared with its focus.

Every lens of the same focal length used on the same plate embraces the same angle of view—it is the focal length of a lens in relation to the plate that determines the angle included. Straight lines joining the different points in the object which is to be photographed and the corresponding points in the image pass approximately through a point that is in the centre of the diaphragm; this point is called the perspective centre of the lens.

Perspective centre of the lens.

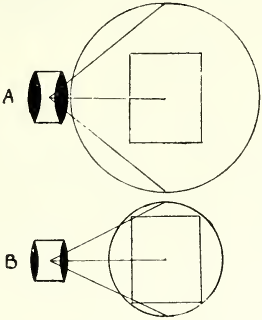


Figure 69.

Let A be a lens of 5-inch focal length, illuminating a circle of 10 inches, i.e., 90°, while B, though of the same focus, illuminates but a 6-inch circle, they will both illuminate a $\frac{1}{4}$-plate, and the angle of the picture photographed, as indicated in figure 69, will be the same, namely, about 46°, but if the lens A had been used on a larger camera, 90° might have been included. A $4\frac{3}{4}$-inch Beck-Steinheil Orthostigmat is generally used on a quarter-plate, and is then a medium angle lens embracing some 46°, whereas it will cover a 7 × 5 plate, and is then a truly wide-angle lens including over 80°. It would hardly be fair, therefore, to say this lens is not a wide-angle one, merely because it is not always used as one.

Method of stating angle of view.

When speaking of the extent of the angle of view in relation to the plate used there are two methods of stating it, which produce different results. In the first case the angle subtended is measured by the base line of the plate AB (figure 70), in the second by CD, which is the diagonal of the plate. It is clear that if the plate be twisted round CD is longer than AB, and as either AB or CD

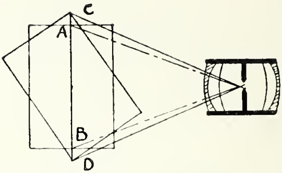


Figure 70.

may be taken, there can be two readings; for instance, a 5-inch lens on a $\frac{1}{4}$-plate will include either 46° or 57°, according to whether the base or diagonal of the plate be considered. The diagonal measurement is only useful in the selection of a lens. It is essential that its angle of view, in other words, its area of illumination, should be sufficient to include the corners of the plate. But the measurement of the angle of the picture itself is always considered from the longest side of the plate AB, and not its diagonal. Suppose the horizon falls, as is usual, parallel to the base, it is clear that the only sensible method to adopt in expressing the angle of the picture is the base of the plate, which describes the extent of the horizon. It is true that objects do exist at the corners of the plate, but until it is customary to use the plate tilted so that the horizon stretches from corner to corner it is unlikely that the measure of the angle of view included will be expressed in any other way.

Classification of lenses.

Lenses are classified as wide, medium or narrow angle, according to the diameter of the maximum circle they illuminate, but the angle of view included in the photographs taken with them is the length of the base of the plate compared with the focus of the lens.

If the equivalent focus of a lens be divided into the longest side of the plate used, or into the diameter of its circle of illumination, the angle included in the picture in the first case, or the utmost possible angle that could be included in the latter case, can be determined at once by reference to the attached table.

Table of angles of view.

If the quotient is	The angle is	If the quotient is	The angle is	If the quotient is	The angle is
	Degrees.		Degrees		Degrees.
·282	16	·748	41	1·3	66
·3	17	·768	42	1·32	67
·317	18	·788	43	1·36	68
·335	19	·808	44	1·375	69
·353	20	·828	45	1·4	70
·37	21	·849	46	1·427	71
·389	22	·87	47	1·45	72
·407	23	·89	48	1·48	73
·425	24	·911	49	1·5	74
·443	25	·933	50	1·53	75
·462	26	·954	51	1·56	76
·48	27	·975	52	1·59	77
·5	28	1·	53	1·62	78
·517	29	1·02	54	1·649	79
·536	30	1·041	55	1·678	80
·555	31	1·063	56	1·7	81
·573	32	1·086	57	1·739	82
·592	33	1·108	58	1·769	83
·611	34	1·132	59	1·8	84
·631	35	1·155	60	1·833	85
·65	36	1·178	61	1·865	86
·67	37	1·2	62	1·898	87
·689	38	1·225	63	1·931	88
·708	39	1·25	64	1·965	89
·728	40	1·274	65	2·	90

Example.—Given a lens of 13 inches equivalent focus; required, the angle included by it on plates respectively 3¼ × 4¼, 4¼ × 6½, 6½ × 8½, 8 × 10, 10 × 12, and 11 × 14.

(1.) Dividing 4·25 by 13, we have as quotient ·327—midway between the decimals ·317 and ·335 of our table; therefore the required angle is 18° 30′. Similarly:

(2.) 6·5 ÷ 13 = ·5; corresponding to 28 Degrees.
(3.) 8·5 ÷ 13 = ·654; ,, ,, 36 ,,
(4.) 10 ÷ 13 = ·77; ,, ,, 42½ ,,
(5.) 12 ÷ 13 = ·923; ,, ,, 49½ ,,
(6.) 14 ÷ 13 = 1·08; ,, ,, 57 ,,

Nomenclature of lenses.

Lenses that will include angles from 3° to 10° are special narrow-angle lenses, such as telescope objectives and telephoto lenses. Those including angles up to 35° can be considered as ordinary narrow-angle, those up to 60° as medium-angle, and those up to 90°, 100° or more as wide-angle lenses.

Effect of the angle of view:—The obvious advantage of making a lens with a wide angle

Effect of angle of view

is that it may be used on a large plate as compared with its focus, and thus include an extended angle of view when it is necessary to do so. There is, however, another advantage scarcely less important.

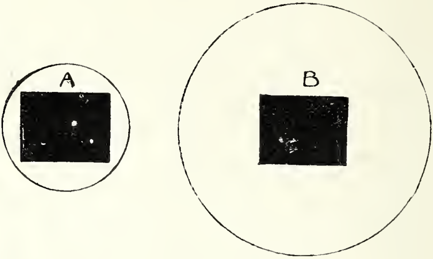


Figure 71.

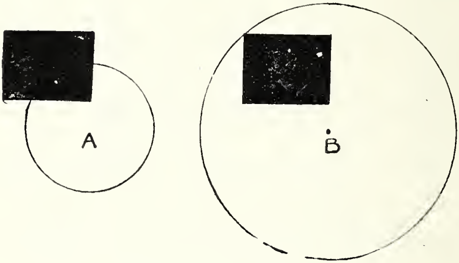


Figure 72.

Cross and rising fronts.

Let A and B (figures 71 and 72) represent the circles of illumination of two lenses of the same focus, say 6 inches, and including two different angles of view, A 56° and B 90°. The diameter of their respective fields will be 6 inches and 12 inches. In figure 71 the centre of the plate (a $\frac{1}{4}$-plate) coincides with the axis, and both lenses cover it equally well. In figure 72 the axis of the lens is dropped 2 inches and moved at the same time 2 inches to the right (or the plate to the left). This represents the combined use of the cross and rising front. Now, in A (figure 72) the plate is only partially covered, and a photograph taken under these conditions would be useless. While in B, owing to its larger circle of illumination, it covers the whole plate. It is quite fair to catalogue the lens A as covering a ¼-plate, which is strictly correct, but when it comes to actual practice the comparative value of the two lenses is by no means the same.

There are so many cameras where a rising and cross front is fitted, that, before purchasing a lens, the maximum angle of view or the circle of illumination should be ascertained. The following table will show the minimum circle required when a rising or cross front is in use.

Table of minimum circles of illumination and angles of view.

Plate in use in inches.	Focus of Lens in inches.			Maximum amount of rising front required in inches.			Minimum circle of illumination necessary in inches.			Extreme angle of view.		
4¼ × 3¼	4¾	5	5½	1	1¼	1½	6½	6¾	7½	67°	67°	68°
5 × 4	5½	6	6½	1½	1½	2	8	8	8¾	72°	67°	68°
6½ × 4¾	6½	7	7½	2	2¼	2½	10½	10¾	11	78°	74°	72°
7 × 5	7¾	8¼	9	2½	2½	2½	11½	11½	11½	81°	69°	65°
8½ × 6½	9½	10¼	11	3	3¼	3½	14	14½	14½	72°	70°	66°
10 × 8	13	16	18	3½	4	5	16½	17½	19	65°	58°	53°
12 × 10	14	18	22	3½	4	6	19½	20	23	68°	59°	56°

Rapid wide-angle lenses.

Many lens makers state the circle of illumination or the extreme angle of view of their lenses, from which, in combination with the above table, the most suitable lenses for general work can be selected. For example, the Series I. Beck-Steinheil Orthostigmat includes 85°, although it is only listed as suitable for a ¼-plate; it can, therefore, be used for ¼-plate or even 5×4 with movement of the rising front of an inch or more. It may be expected from the above that a lens, for whatever purpose it is to be used, should possess a large angle. This is theoretically true, but to make a rapid lens embrace a wide angle is a costly and difficult matter, involving as it does larger lenses and better corrections, and it has only been satisfactorily accomplished in a few types, such as the Orthostigmats, Anastigmats, Biplanats, etc. If these lenses are not employed wide-angle lenses must be used for wide-angle work. If no rising front is to be used a narrow-angle lens will do quite as well.

Perspective in photography.

The question of the most suitable angle of view to include, in order to produce the most pleasing picture, introduces the interesting subject of perspective in photography and its bearing on focal length. There is probably no other subject round which such a bitter war has been waged as that of perspective in photography and the artistic qualities of a photograph. Some workers declare, in the words of Dr. Emerson, that—

Extract from Dr. Emerson's Naturalistic Photography.

> Far too much time has been given and too much importance attached to the subject of optics connected with photography. Much time and expense would have been saved had the pioneers of photography had a good education. . . . It is, indeed, a satire on photography which can never be entirely removed, that at the very time the so-called scientific photographers were worrying opticians to death and vieing with each other in producing the greatest untruths, that they were all the while shouting in the market-place that their object was to produce truthful works. At length when the most doubly patented distorting lenses were made to meet their demands, they presented a sharp untrue picture, "Finer than the eye could see," some said. . . . Had they taken up the simplest form of lens and used it as a magnifying glass, they would have seen that all was not right, and instead of clamouring for the lies of depth of focus, wide angle, brilliancy and other hydra-heads of vulgarity, they might have set to and made the lens which was required.

And yet, in spite of Dr. Emerson, no one has yet learnt what that lens is!

If the motif of the vast majority of photographers is considered, will it not be generally conceded that their object is not to produce results approximating to Rembrandt or Turner, but rather to preserve a record as pleasing as possible of some transient phase of nature or some scene left behind? Many photographs are records of vanished things, are the concrete of memories, some pleasant, some unpleasant, all passing. They are leaves from the notebook of the past, some of interest sufficiently lasting to find them a place on our walls, where they vie with any monochrome as a work of art. In all cases an effort should be made to obtain as artistic and pleasing a result as possible, and nothing is of greater importance in this respect than a judicious choice of point of view and focal length of lens. It may be accepted as a sound maxim that the longest focus lens possible under the circumstances will produce the best perspective and the least distortion. Narrow-angle pictures can be viewed at any distance without unduly exaggerating the perspective, while to get a truthful representation of the work done with a wide-angle lens, it must be viewed at a distance equal to the focal length of the lens with which it was taken.

Effect of focal length on artistic work.

Narrow and wide-angle pictures.

Figure 73 will elucidate this; let XX^3 be a photograph which has been taken with a lens

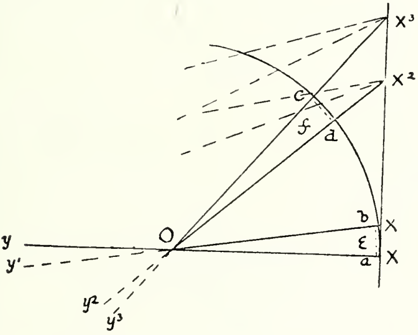


Figure 73.

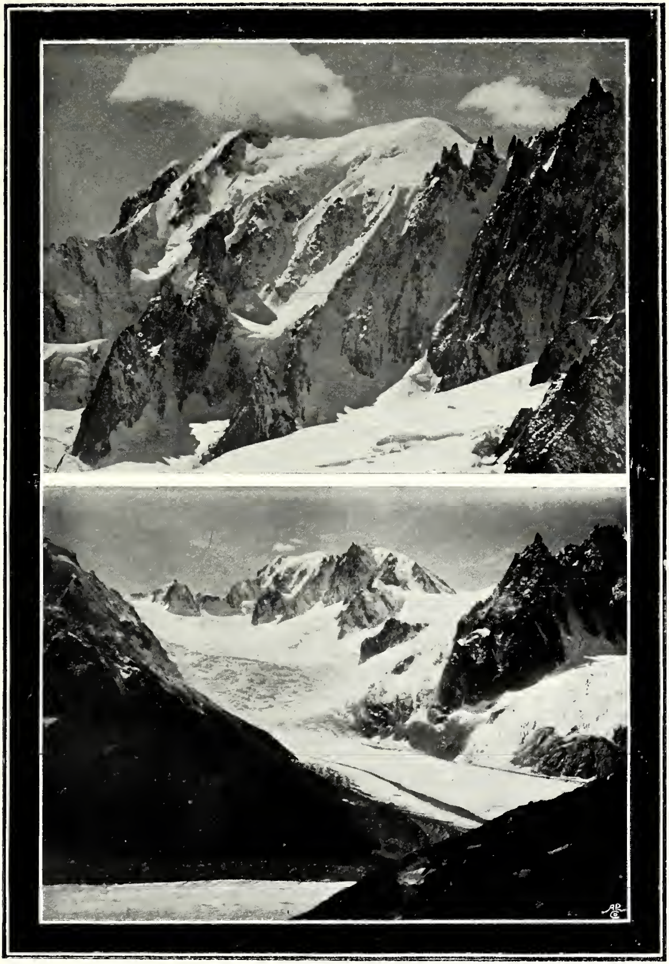
at O. The observer at O, when looking at the landscape in the direction of YY^1Y^3, will see the same view as was photographed by the lens; if the observer is then turned round, still retaining his position in the optical centre of the lens at O and examines the photograph on the plane XX^2X^3, it will see in the photograph a perfectly accurate reproduction of the landscape with correct perspective rendering. If (a b) is the measure of some object in the picture plane subtending an angle (e) to the eye at O, and (f) be a similar angle from the margin of the field; it follows that (c d) will be the same length as (a b), and if Oc and Od are produced they will meet the picture plane in X^3 and X^2, and X^2X^3 represents a larger object than does XX^1. In the case illustrated it represents an object that is actually twice as large, but which only appears to be the same size to the eye at O, and quite correctly so. If, however, the eye is now placed in such a position that it is considerably further away from the photograph to the left of O, it is evident that the object X^2X^3 will appear larger than XX^1, although when viewed at the correct position (the perspective centre of the lens), they were the same size. This explains why the perspective rendering will only be strictly accurate when the photograph is viewed at a distance equivalent to that of the focus of the lens which took the picture. If the eye be removed from the picture to a considerable distance, the difference in the relative sizes of X^2X^3 and XX^1 will be but slightly altered by a further movement, so that if a moderately long focus lens is employed the position of the spectator is not of such importance; and the worst defects of exaggerated perspective are only met with in lenses whose foci are very short as compared with the size of the picture.

If a 3-inch lens is used on a ½-plate it gives an angle of about 90°. It will be totally impossible to view the resultant picture at a distance 3 inches from the eye, so that it is certain to show incorrect perspective. There are cases where it is necessary to use a wide-angle lens in order to include a sufficient amount of view,

See page 234.

PLATE XXV.

Mont Blanc from Le Couvercle.



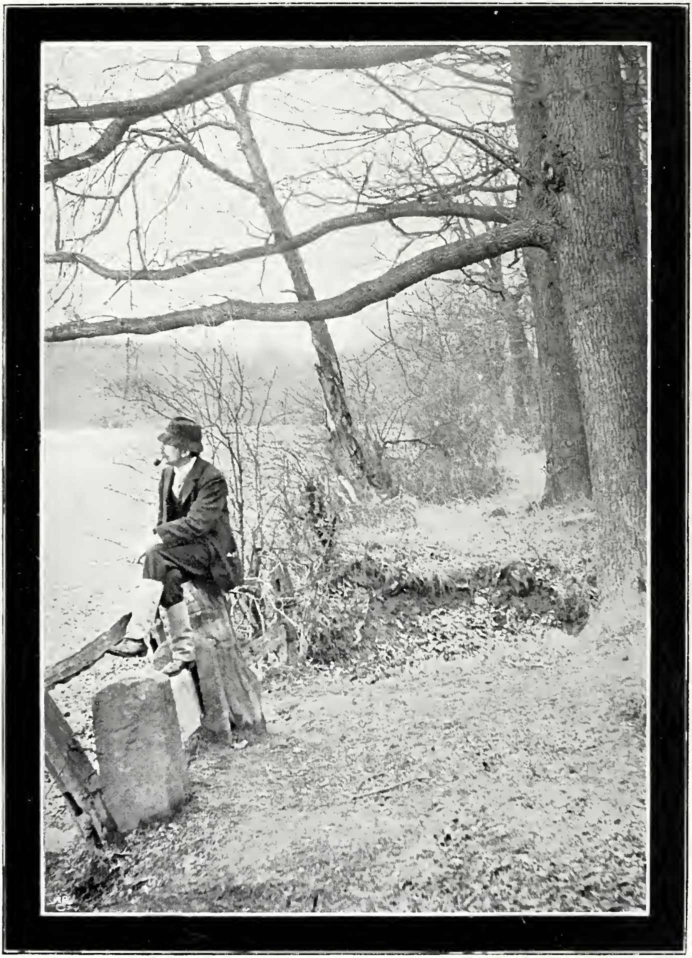
Negative by *W. T. Lister.*

The top of the two pictures is a telephoto picture (5½ times) of the lower. Beck-Steinheil Telephoto attachment and Beck-Harris screen used.

See page 178.

PLATE XXVI.

THE POACHER.



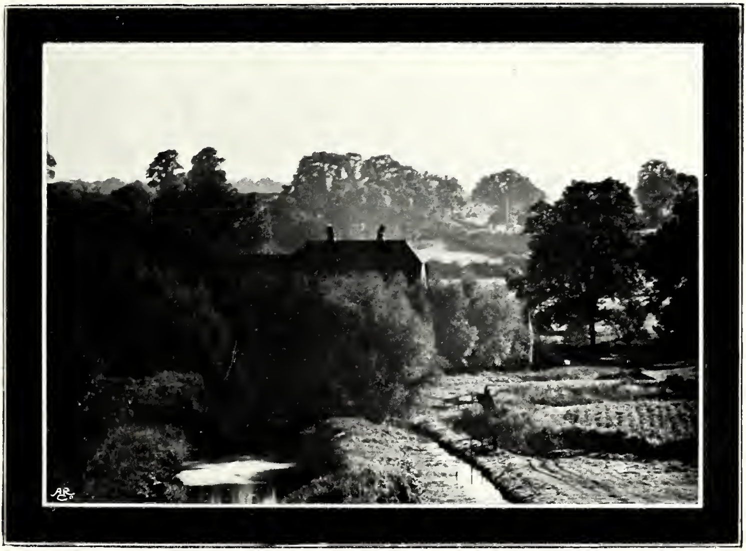
Negative by *W. Beck.*

From a photograph taken with a 5½-inch Beck-Autograph Lens. Rack and pinion focussing motion used.

See pages 183.

PLATE XXVII.

THE OLD MILL, ST. ALBANS.



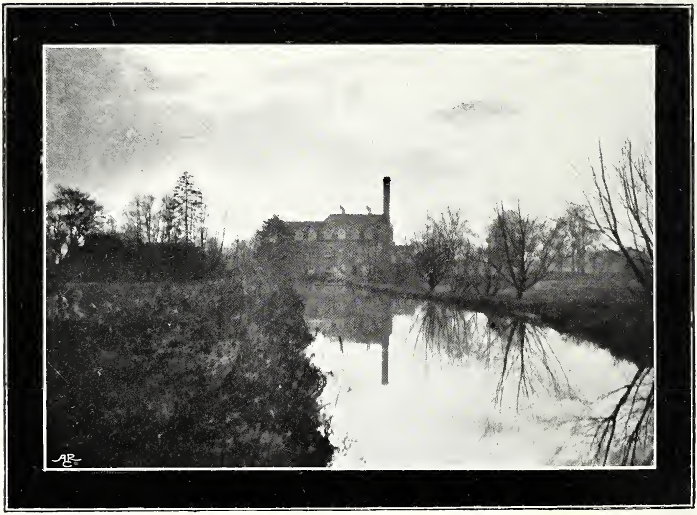
Negative by *W. H. Wilkins.*

A telephotograph taken with a No. 5 Beck-Steinheil Orthostigmat and a standard power attachment. Magnifying power 8 times, resultant equivalent focus 56 inches.

See page 183.

PLATE XXVIII.

THE OLD MILL, ST. ALBANS.



Negative by *H. Andrews.*

A photograph of the same mill as plate XXVII., only taken with a 7⅛-inch lens on a ½-plate.

but where this is done the picture should be so composed that it does not depend upon the perspective for its interest. A view including a church spire may require the use of a wide-angle lens, and if there are not other objects nearer or further away, included in the composition, the poor perspective will be of little consequence. It must be remembered that perspective only exists where the objects or parts of them are at different distances from the observer. A map or bird's-eye view has no perspective; and the more nearly all the objects are at the same distance from the camera, the less becomes the importance of correct perspective rendering. If purely pictorial results are sought for, an angle of more than 35° or 40° should not be included. Good paintings rarely include more, but the mere fact of including only a small angle does not mean that artistic work will result. There is no advantage to be gained by laying down rules—rules will not produce artistic results by themselves, and every rule has been successfully infringed by great artists.

When a wide angle may be used.

A good series of lenses for a complete outfit would comprise—

An outfit of lenses.

(1) A wide-angle lens with a focus $\frac{1}{4}$ less than the longest side of the plate.
(2) A rapid lens* about $1\frac{1}{2}$ or $1\frac{1}{3}$ times the longest side of the plate.
(3) A rapid narrow-angle lens about twice the length of the plate.
(4) A telephoto attachment† to use with No. 2.

ABSORPTION, SCATTERING AND REFLECTION.

A lens absorbs a certain small proportion of the light which enters it, because glass is not absolutely transparent.

---

* The rapid lens might be of the convertible type, in which case the single combinations could be used as longer focus narrow-angle lenses. The advantage of a convertible set of this kind is its portability.

† See Section III. for the particulars of the properties of this lens.

Definition of absorption.

When describing achromatism reference was made to the fact that white light is composed of a great number of rays having different wave lengths which produced on the eye varying sensations, indicative of different colours. If a ray of white light be made to pass through a piece of brilliant red glass, the sensation produced on the eye is that of a red colour, because only the red rays pass through the glass without being absorbed. The rays which affect the sensitive salts of silver are those at the green and blue end of the spectrum, and so if the lens were made of red glass it would stop all these rays, and it would be so slow as to be useless. This is actually what happens in a minute degree when light passes through glass of any kind, however thin, the degree varying with the purity of the glass and, to a less degree, its thickness.

Effect of coloured glass on white light.

The clearer and more colourless the glass which is used in the manufacture of the lenses, the better and more rapid they will be.

Causes of discoloration.

If a lens shows the least tinge of yellow it will be slower than if it does not. There are two classes of discoloration due to deterioration which may occur with the lapse of time. The first is in the material (usually balsam) used to cement the components of a compound lens system, and the second is the glass itself. The first need not be considered, for in the best modern lenses the film of balsam is so thin and has been so carefully bleached that discoloration due to this cause would not be likely to occur. The second is of rare occurrence, but should be borne in mind. In the densest glasses which, however, should not be used for lenses, there is a slight tendency to yellowing if exposed to the sun or bright light for any length of time. This is most likely due to the presence of manganese and iron, and a process of oxidation is set up by the light resulting in this discoloration. It will be noticeable when unstable glass is on the outside, for in this case moisture will materially hasten the oxidizing process, and a finger mark, if left on the lens, may result in a brown stain. No lens should be touched with a hot finger. Figure 74 shows an arrangement of the glasses in which one unstable glass is safely enclosed between two harder ones, which are not affected by heat or damp.

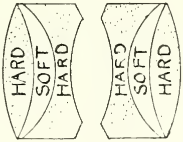


Figure 74.

A method of testing the colour of lenses.

Some of the older types of lenses, when placed on a sheet of white paper, show that they are made of a glass that is far from being transparent. Glass of different kinds absorb varying parts of the spectrum, and it is essential that the manufacturer should choose those kinds which are most transparent to the ultra violet, blue, and green rays. Rock crystal is known to be almost entirely transparent to these rays, and for this reason it is used in the lenses or "compressors" required for the light cure of Lupus, but it is useless as a material for making photographic lenses on account of its double refraction.

REFLECTION.

Reflection.

This is of more importance than the colour of the glass to the photographer who is purchasing a lens, as modern lenses are wonderfully free from colour defects.

Reflection may play two parts in a photographic lens. It may, by reflecting back part

Effect of highly curved surfaces.

of the light which should have entered the lens, reduce its rapidity, or it may reflect light into the camera, causing milkiness or even flare (see page 78). Certain complicated modern lenses have highly-curved surfaces, and if these be air surfaces there may be a distinct loss of light, either from the fact that some of the rays of light never reach the plate or reach some part of it that they ought not to.

Figure 75 represents an imaginary lens with 10 air surfaces, in which the opportunity is greatly increased of having a portion of the pencil of rays AA so reflected, that they do not come to a focus at X. The more obliquely the rays strike the surfaces, the larger is the percentage that is reflected and the smaller the number that is refracted. When an oblique ray, as AA, has to encounter a large number of air surfaces it will suffer a slight loss at each, and the amount that reaches a focus at X will be less than in the case of a similar pencil in figure 76, where there are but

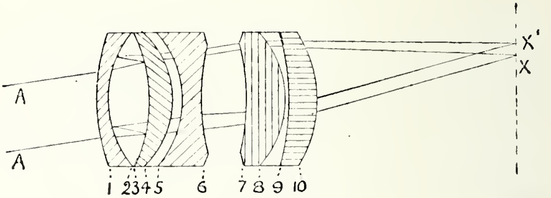


Figure 75.

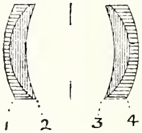


Figure 76.

four. The loss from the cemented surfaces

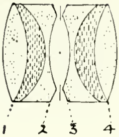


Figure 77.

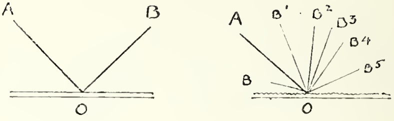
is too trifling to be considered. Thus, a lens such as that in figure 77, with only four air surfaces, will not lose more light from this cause than the lens shown in figure 76. Returning to figure 75, it may be interesting to explain what becomes of the rays. A certain number never pass the lens, but are reflected out and lost. Some, on the other hand, pass through surfaces 1 and 2, and are refracted in the ordinary way. On meeting the surface No. 3, however, the rays strike it too obliquely and are reflected back again (as indicated by the fine line) to surface 2, thence once more to surface 3, which this time they pass through and are refracted; they have been slightly displaced owing to this internal reflection and do not arrive at a focus at X but at X′, some little distance from X. This may happen at any one of the surfaces, resulting in a number of false images; these detract from the brilliancy of the true image and give a tendency to milky results. The photographer must not be unduly critical on this question, as practical experience has shown that lenses with even eight or ten reflecting surfaces may give good results, but no treatise on lenses is complete without an explanation of the defect.

False images

SCATTERING.

Scattering.

There may be a loss of light through another cause than the two already mentioned, namely, by scattering. Suppose in figure 78, a ray of light AO strikes a perfectly polished surface



a b

Figure 78.

(a) such as a mirror, it will be totally reflected in one direction, namely, that of OB. If, however, it strikes a rough surface (b) such as a sheet of white paper or ground glass it will be reflected in all directions as OB, OB^1, OB^2, OB^3, in other words, it is scattered. If the surfaces of a lens system are imperfectly polished, that is, if the surface is composed of a number of little grey dots left during grinding, these points act as do the fine particles in the surface of white paper. The ray on striking the surface will be partially scattered, portions only passing through.

Explanation of scattering.

Grey surface.

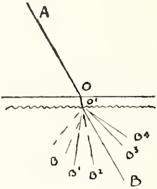


Figure 79

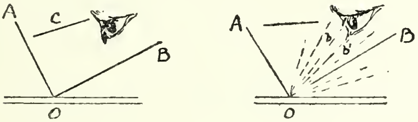
In figure 79 is represented a piece of glass which is polished to a black polish on the upper surface, but badly on the lower; in consequence, the ray AO passes completely through the first surface according to the laws of refraction, but in emerging at O' a portion of it gets scattered in all directions as B, B^1, B^2, etc. Great strides have recently been made in optical factories in this respect, and even low-priced lenses have often as perfect a polish as could be desired. In the manufacture of cheap lenses there is a

Polishing.

Figuring.

Grey and black polish.

temptation to leave the surfaces slightly grey, because polishing, unless it be supplemented by the costly process of figuring, is liable to destroy the perfection of curvature, which it is the aim of the optician to preserve. A method of examining the difference between a grey and a black polish can be explained by reference to figure 80 ; if there are two pieces of glass, (a) and (b), the one with a black polish and the other with a grey, and if these are placed on a dark piece of velvet and a beam of sunlight be allowed to fall on the surface as AO, a card being held at C so that no light can be directly reflected into the eye, the ray AO will be reflected as OB. No portion will be received by the eye, and the surface will appear jet black. In the second case, however, although the major portion may be reflected as OB owing to the imperfection of the optical polish, some will be scattered in all directions as indicated by the dotted lines, and a little will find its way to, and be collected by, the eye, to which the surface will appear a trifle grey.



a

b

Figure 80.

NOTE.—This section completes the semi-technical portion of the book. The remaining sections are of more general interest.

BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION IV.

(1) The properties bearing on the use of a lens are—

Focus.
Rapidity.
Depth of focus.
Brilliancy of definition.
Angle of view.
Equality of illumination.
Absorption, reflection and scattering of light.
Area of critical definition.

(2) The focal length of a lens is the measure of its refracting power and of the size of the image it will produce.

(3) This length can be chosen to suit any set of circumstances.

(4) This length is about the distance of the diaphragm of a rectilinear, or the back surface of a single view lens from the ground glass, when objects at a great distance are in focus.

(5) By depth of focus is meant the power of a lens to sharply depict more than one plane of the view upon the plate.

(6) By 'sharply' is meant that a point in the object is represented by a circle in the image not more than 1-100 inch in diameter.

(7) There are 3 factors governing the amount of depth of focus; they are—

(1) The focal length of the lens.
(2) The aperture of the lens.
(3) The amount of spherical aberration present.

(8) The shorter the focus the more the depth of definition.

(9) The smaller the aperture, the greater the depth.

(10) The presence of a little spherical aberration means an increase in depth of definition.

(11) A lens possesses rapidity, a pinhole does not.

(12) With two lenses of the same focus, the one with the largest aperture will be the most rapid.

(13) Rapidity is written as the diameter of the effective aperture divided into the focal length.

(14) Brilliancy of definition means black must be black, and white, white, but neither grey.

(15) The fewer the reflecting surfaces the better is the brilliancy.

(16) Only those surfaces that are not cemented count.

17) The worse the polish, the less the brilliancy.

(18) That part of the picture that is sharp is known as the area of critical definition.

19) The better the quality of the lens, the larger this area.

(20) The smaller the stop, the larger the area of critical definition.

(21) The longer the focus of the lens, the larger the area.

(22) The modern orthostigmat (anastigmat) has a larger area of definition in proportion to its focus than any other type of lens at the same aperture.

(23) If a lens illuminates the edges of the field as brilliantly as the centre, the illumination is perfect.

(24) There is no lens that does this absolutely.

(25) The farther apart the lenses of a doublet, the worse the illumination.

(26) The larger the lenses in proportion to the diaphragm, the better the illumination.

(27) The smaller the stop, the more even the illumination.

(28) Angle of view is the amount a lens will include in the picture.

(29) A lens that can take in only a small amount is a narrow angle lens; one that will include more if used on a large plate a medium angle; and one that takes in a large expanse a wide-angle lens.

(30) The angle of a picture is measured by the longest side.

(31) There is no fixed law as to the most suitable angle to include.

(32) A small angle gives a better pictorial result.

(33) If a wide-angle lens has been used, the picture should be viewed from a distance equal to the focus of the lens with which it was taken; if it is not the perspective will be wrong.

(34) If a narrow-angle lens be used, it can be viewed from any distance without disturbing the perspective.

(35) To be ready for all emergencies a number of different foci lenses should be carried, varying from $\frac{3}{4}$ to twice the longest side of the plate, and in addition a telephoto attachment.

(36) If the glass of which a lens is made is not absolutely transparent, it will absorb a small portion of the light on its way to the plate.

(37) None of the blue and violet rays must be absorbed, or the lens will be rendered less rapid.

(38) There are two ways in which a lens may become deteriorated in this respect—

(a) The cement used to join the combinations may become yellow.

(b) The glass of the lenses may become yellow through oxidation.

(39) Finger marks on the lens surfaces may result in brown stains.

(40) Reflection will reduce the rapidity of a lens, either by reflecting some of the rays that should form the image back again out of the lens, or by distributing them indiscriminately into the camera, where they tend to make the picture look milky.

(41) The greater the number of air surfaces, the greater the chance of this result.

(42) If a surface is not polished to a black polish some of the light, instead of passing straight through, will be scattered. A surface like this is called a grey surface.

SECTION V.

TYPES OF PHOTOGRAPHIC LENSES.

Nomenclature of lenses.

The earlier chapters of this book having dealt with the somewhat technical side, the principles, the manufacture, the corrections and properties of photographic lenses, the present section will roughly classify lenses into their different types, pointing out the characteristics of each form.

Evolution of the lens.

The photographic lens of the present day has been evolved step by step during a period of over 50 years. The advance has been due to the inventions of many independent and competing optical firms, who have created new names for each succeeding lens that has been invented. It is, therefore, not to be expected that the nomenclature has followed any very definite scientific plan, but names have gradually come to be recognised as describing particular types and have been adopted by the trade in general. Originally there was no reason why the rectilinear should not have been called an anastigmat or *vice versa*, but usage has pointed to some boundary line to limit the use of the terms, and that being the case, it should be adhered to. As things stand, it would not be correct for a maker to describe an anastigmat as a rapid rectilinear, or *vice versa*.

General types.

The names for the types which are in most general use, and which will be adhered to throughout this work, are—

(1) Single non-achromatic, S.N.A.
(2) Double meniscus, Periscopic, D.N.A.
(3) Single achromatic, S.V. (double and triple).
(4) Petzval portrait.
(5) Rapid rectilinear, R.R.N.A.R., M.A.R., W.A.R. (narrow, medium and wide angle).
(6) The unsymmetrical anastigmat.*
(7) Universal orthostigmat (anastigmat).

As it is useful for trade purposes to distinguish between the lenses of different makers, numbers of other names are in use to denote the particular manufacturer's own form, but from this great variety lenses can be identified and placed in one of the above groups without much difficulty.

Non-achromatic lens.

(1) THE SINGLE NON-ACHROMATIC LENS, S.N.A. (figure 81).

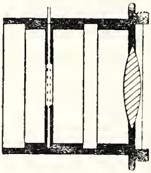


Figure 81.

Diagram of corrections.

This is seldom supplied under any specific name; it may be openly sold for producing fuzzy pictures for those who love impressionistic art. It may be supplied with a small stop on the cheapest cameras. A glance at the diagram (figure 82) will show that it is quite uncorrected for colour; it has, therefore, a chemical focus, and, if used on a camera with a focussing screen, it will have to be adjusted for this error. It is equally bad except at small apertures for spherical aberration, astigmatism and curvature of field, and a stop as small as f/32 is necessary to give definition. In one direction only is this lens satisfactory, and that is with reference to optical flare. Its uses are proportionately limited.

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* This heading includes those unsymmetrical lenses of a more complicated kind than the well-known double orthostigmat. They possess a greater number of air surfaces, and are rarely so designed that their single components can be used as perfectly corrected landscape lenses of a longer focus than the whole.

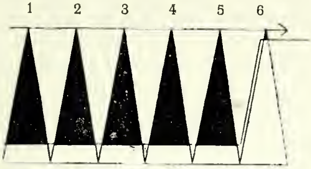

Figure 82.

The height of the intermediate line marks the degree to which the errors are corrected; the less "black" that appears, the less room for improvement.

Corrections of the S.N.A. lens.

As a photographic lens for serious work the S.N.A. need not be taken into account. Its chief use is as an auxiliary for altering the focus of better corrected lenses of some other type, as exemplified in the Frena system of "magnifiers."

Magnifiers.

(2) THE DOUBLE MENISCUS, D.N.A. (figure 83).

Double meniscus.

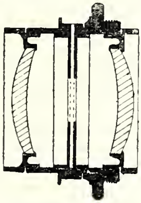

Figure 83.

This name is descriptive of the double non-achromatic lens. The double meniscus is entirely uncorrected for colour and, therefore, like the spectacle lens, has a chemical focus, and can only be satisfactorily employed on fixed focus cameras or those with scales and no ground glass; its corrections in other respects are a great advance on the single lens, and it can be used satisfactorily with a moderate

Qualities of the double meniscus.

stop. There is one interesting point that will occur in using any lens that has a chemical focus — however accurately the focussing is done, so that the plate shall be in the plane of the most chemically active rays, if a full exposure is given some of the other rays that do not come to this focus will have had time to act and a slightly blurred picture will result. The double meniscus usually consists of two deep meniscus components as indicated in figure 83, with the diaphragm placed between them.

Diagrams of corrections and properties.

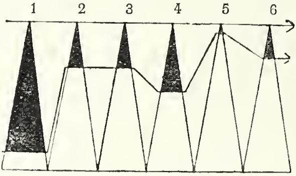

Figure 84.

1. Chromatic aberration.
2. Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

The height of the intermediate line marks the degree to which the errors are corrected; the less "black" that appears, the less room for improvement.

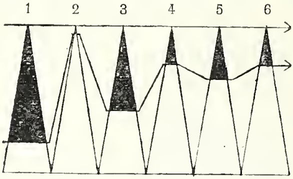

Figure 85.

1. Rapidity.
2. Depth of definition.
3. Equality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by an absence of "black."

Corrections of the double meniscus.

A 5-inch lens covers a quarter-plate at f/16 satisfactorily. An examination of figure 84 will show the salient features of this lens. The chromatic error is, of course, bad; the spherical aberration is fairly well corrected at this aperture, astigmatism is partially attended to. There is a good deal of saucer-shaped curvature of field, but there is very little distortion over a moderate angle and very little chance of flare.

Its general properties are sufficiently indicated in figure 85, and do not call for any special comment.

(3) THE SINGLE ACHROMATIC LENS, S.A. or S.V.L. (figures 86 and 87).

Single achromatic lens.

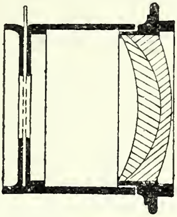

Figure 86.

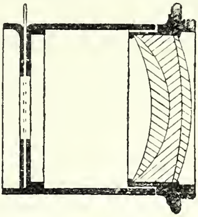

Figure 87.

Under this name are included those lenses which, although perhaps composed of as many as four separate lenses cemented together, yet form but one complete "single" lens with the diaphragm placed in front. Single view, landscape and other names denote the same lens; this was the earliest type used in cheap cameras and is still very popular.

Different forms of single lens.

In figure 87 is illustrated a triple form which can be dismissed for the moment. It covers sharply a larger plate than the ordinary double cemented single lens and gives beautifully even illumination. It used to be popular for landscape work where the maximum of brilliancy was required over a large angle, but it has been discarded on account of its distortion. Single lenses are now only used for moderate angles where this distortion is less noticeable, or for the sake of cheapness.

Construction of the S.A.V. lens.

Figure 86 is a typical single lens. It is composed of two glasses, whose curvature resembles that illustrated, and of light and dense flint or flint and crown glass, the latter usually being the positive element. It is the form of lens referred to earlier, as being made with a definite view to correcting the chromatic and spherical error, and it is for this reason that it is known as the single achromatic lens, S.A.L. The chief opticians prefer their own forms, but the same principles underlie the construction of all. It has been shown of recent years that, however good the formula of a lens may be theoretically, it will not produce good results unless the subsequent operations are carried out with the utmost care. It is for this reason that, although constructed on a simple formula, where one would imagine there was little chance of variation, there are differences in the quality of individual single lenses. To illustrate this point, the reader should refer back to plates IV. and V., which are produced with lenses taken from two different makes of hand cameras now on the market.

Differences in S.A.V. lenses.

In figures 88* and 89* are diagrammatically

Diagrams of corrections and properties.

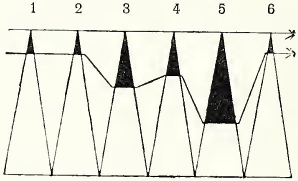

Figure 88.

1. Chromatic aberration.
2. Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree to which the errors are corrected ; the less "black" that appears, the less room for improvement.

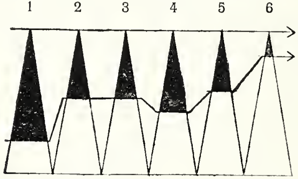

Figure 89.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by the absence of "black."

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* Figures 88 and 89 should be compared with the corresponding diagrams of corrections and properties of the other types, for purposes of estimating the merits of each.

represented the degree to which the corrections are carried in this type of lens, and their resultant properties: a comparison can then be made between this type and the two former. It must rank above the double meniscus because it has no chemical focus, it need not be confined to use in box cameras, but can be used with the ground glass, its maximum rapidity being about f/11. A 5½-inch lens will cover a ¼-plate sharply at f/11, but will give barrel-shaped distortion at the outer edges of the plate.

Referring back, plate IX. shows that it is possible to procure an example of this lens in which the distortion, its greatest drawback, is hardly noticeable; in fact, when the lens has as little as this it can be usefully employed for architectural photography.

More complicated single lenses

More complicated single lenses have been placed on the market, but there does not seem much advantage in these triple and quadruple combinations, the only excuse for their introduction seeming to lie in the fact that their resultant images are slightly more brilliant than those produced by a lens with more than two outside surfaces, but they do not equal the rectilinear type in other respects. It is impossible to show this difference in plates reproduced by the half-tone process, for the brilliancy of both would be so impaired in the block as to render a comparison unconvincing. Single combinations of some of the double anastigmats are convenient, and especially satisfactory as narrow-angle lenses; those of the Orthostigmat Series I. or II., for instance, can be used as single lenses, and in this capacity possess many advantages over the older form. The field is flat, while for portraiture at full aperture they are in many respects unique, and the distortion is slight.

Use of single combinations of orthostigmats.

Plate X. represents the results obtained by using the half combination of an 11-inch orthostigmat lens. The plate shows no curvilinear distortion, although a large angle is included. These "half" lenses are almost free from distortion when the stop is in its normal position; but the area of sharp definition can be increased by somewhat increasing its distance from the lens.

(4) THE PORTRAIT LENS (Petzval form), figure 90.

The Petzval portrait lens.

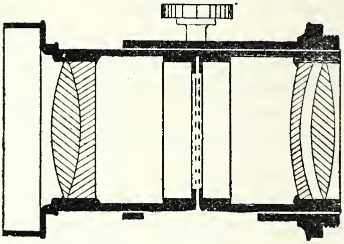

Figure 90.

Under the heading of portrait lenses, all lenses used for portraiture might have been included, but certain forms of rectilinears and orthostigmats mentioned under their own heads, are coming more and more into use for this work. To simplify the classification, the original Petzval lens in its various forms, is the only one treated under this heading.

The light in the studio must be reduced by blinds and screens in order to obtain a well-modelled picture, and in the earliest days of photography the lengthy exposures required by the Daguerreotype and wet plate processes, when a single lens was used, threatened to restrict the ultimate possibilities of the new craft.

Professor Petzval.

In 1866 Professor Petzval, of the Vienna University, had his attention drawn to this fact, and endeavoured to produce a lens which should primarily have a much greater intensity (rapidity) than the old single lens, and also give better central definition. The portrait lens bearing his name is the result.

In figures 91 and 92 are diagrammatically represented the extent to which the various corrections are carried and the value of the different properties in this type of lens. In figure 91, the "corrections" of this type will be easily recognised, and require no special comment. Figure 92 indicates the "properties" of this lens at a glance; it reaches the ideal in point of rapidity, having a full aperture of from f/3 to f/4. This extreme rapidity is absolutely essential in many subjects with which the professional is brought face to face. In the Petzval type of portrait lens the central definition is specially good, though the softer definition of the extra rapid rectilinear is to-day preferred by the more artistic workers. At the time the Petzval was intro-

Diagram of corrections and properties.

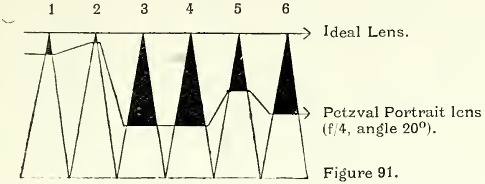

Figure 91.

1. Chromatic aberration.
2 Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree to which the errors are corrected; the less "black" that appears, the less room for improvement.

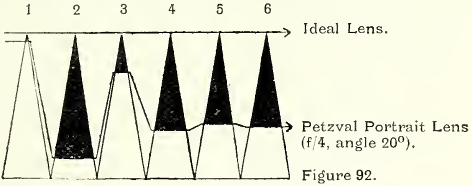

Figure 92.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by the absence of "black."

Disadvantages of the Petzval for portraiture.

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* Figures 91 and 92 should be compared with the corresponding diagrams of corrections and properties of the other types, for purposes of estimating the merits of each.

duced the cry for greater rapidity was coupled with a demand for better definition, which is one reason for the peculiarly stereotyped results of the vast majority of early professional portraits. There is now a sign of the "regulation" Carte-de-Visite or Cabinet portrait giving way to the richer modelling and finer feeling of the work produced by the extra-rapid rectilinear lenses, whose softer definition and greater depth are preferred.

Use as a projection lens.

The Petzval lens possesses some distortion, and it cannot be successfully used with a small stop, as it has a tendency to give bad flare. It gives very unequal illumination, a fault which renders it unsuitable for landscape or field photography; it is, in fact, of little use outside the studio except as a projection lens.

(5) THE RAPID RECTILINEAR (figures 93 and 94).

Rapid rectilinear.

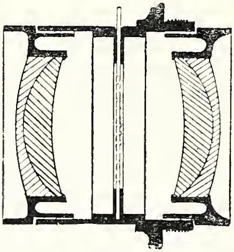

Figure 93.

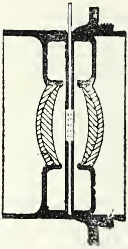

Figure 94.

No other lens has in the past been so popular as the rapid rectilinear; it was the first corrected lens to overcome the troubles of distortion coupled with a large flat field. This type includes, besides Rectilinears, the Biplanats, Aplanats, Rapid Symmetricals, Periplanats, Euroscopes, etc. They are made under the name of extra-rapid rectilinears with apertures of f/4, under the name of biplanats with an aperture of f/5·8, under the name of rapid rectilinears, rapid symmetricals or aplanats

Other names for R.R. lenses.

with apertures from f/7 to f/8, of mid-angle or wide-angle with apertures of f/11 and f/16. Lenses of this type generally consist of two similar cemented doublets, (as illustrated in figure 93), with a positive meniscus lens of light flint or crown glass and a negative meniscus of a heavier flint, the diaphragm being placed between the two combinations. By far the greater number are symmetrical, that is, each combination is of approximately the same focus, and about double that of the whole lens.

Steinheil and Dallmeyer.

This form of lens was introduced simultaneously in this country and in Germany by the houses of Dallmeyer and Steinheil, under the names of the Rapid Rectilinear and the Aplanat. Both names are explanatory and accurate, for the lens is rectilinear and rapid when compared with the other lenses of its day, and the word aplanatic signifies, that points in the object are brought to points in the image plane, and bear the same relation to one another in that plane as they do in the object, and this only over a limited angle. This precludes aplanatic lenses as such, from being called anastigmats, but does not prevent anastigmats from being aplanatic. The rectilinear is a rough approximation to a hollow spherical lens. It carried the idea of perfect corrections for oblique rays as far as was formerly considered possible. The modern symmetrical anastigmat represents a somewhat elaborated form of the rectilinear, made on a formula rendered possible only by the advent of new types of glass. The anastigmat may be considered, indeed, as the logical conclusion of the rectilinear type carried to its highest attainable limit. The various names given by opticians to their lenses are often a guide to their chief characteristics. Lenses described as Biplanats are Aplanats with double the normal rapidity, etc.

The rectilinear has been varied in construc-

Narrow, mid and wide-angle R.R's.

tion to render it suitable for a variety of purposes. A lens constructed to cover a large angle is a wide-angle rectilinear, it has a small aperture and very large lenses compared with its aperture. That which covers a less angle is called a mid-angle rectilinear, and one that covers only a very small angle is a narrow-angle or rapid rectilinear. In the same way a lens having a much larger aperture than the normal will be an extra rapid rectilinear. The kind that is most frequently met with is the medium-angle rapid rectilinear with a full aperture of f/8.

Figures 95[*] and 96[*] show the corrections. The chromatic error is so far eliminated that it can be regarded as corrected for all except the most stringent work. Spherical aberration is reduced to such a point, that, it will not be

Diagram of corrections and properties.

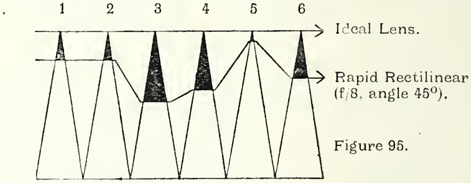

Figure 95.

1. Chromatic aberration.
2. Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree to which the errors are corrected ; the less "black" that appears, the less room for improvement.

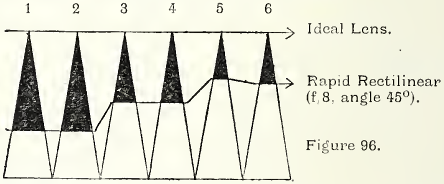

Figure 96.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by an absence of "black."

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[*] Figures 95 and 96 should be compared with the corresponding diagrams of corrections and properties of the other types, for purposes of estimating the merits of each.

objectionable even if the lens is used at its full aperture. There is one important error that is only partially corrected, namely, astigmatism. This will be painfully apparent if the lens is used to its limit of angle—if equality of definition is required over the whole field, it must be stopped down. Thus the rectilinear cannot be used at full aperture if the lens is comparatively short in focus compared with the size of the plate in use.

Why R.R.'s are not universal.

The great increase of the rapidity of shutters and the desire on all hands to do rapid work precludes this type from being universal. The oblique spherical aberration or coma is also somewhat uncorrected, but this error has not been treated of separately as it is generally associated with astigmatism. The curvature of field in the rectilinear is somewhat too marked to allow of the lens being used at open apertures for copying, though if this is reduced a little it makes a first-class lens for enlarging. The wide-angle rapid rectilinear is still the best all-round lens for work for which 90° or more is to be included in the picture. It must be used with very small stops to cover this large angle, and is not so good as the anastigmat for moderate angles. The extra-rapid rectilinear, with its full aperture of f/4 or f/5·8, is probably the finest portrait lens extant, its power of rendering the different planes of the sitter equally sharp but not too brilliantly defined, being of great advantage to the photographer; in addition the extra-rapid rectilinear form of portrait lens makes a good group lens when stopped down, being more satisfactory than the Petzval type for this purpose.

Extra rapid rectilinear and the biplanat.

Differences in quality illustrated by plates.

Needless to say the qualities illustrated in figure 96 vary in individual lenses, and to show the extent of this, plates XII. and XIII. have been prepared. They show the results obtained with two presumably similar lenses, one by a maker of repute and the other a cheap commercial article. It need scarcely be pointed out, that a badly made or indifferently adjusted lens is dear at any price, and, that it is better to have a well-made lens of a less ambitious type than one badly made, but more aspiring in its construction.

Focus of R.R. to cover ¼-plate.

A first-class rapid rectilinear of 5-inch focus will cover a ¼-plate at f/11, while to produce as good results with a cheap lens, even if the central definition is good, a 6-inch or 6¾-inch focus would have to be used, in which case the photographer would have to be content with less depth of definition.

From the above description it will be noted that a good rapid rectilinear lens with an aperture of f/8, or even a biplanat with an aperture of f/5·8 will, if the price of the anastigmat be found prohibitive, make an excellent all-round lens for the photographer, but it must be by a maker with a reputation, for the market is flooded with cheap foreign rectilinears which give results inferior to well-made single achromatic lenses.

R.R. and telephoto attachment.

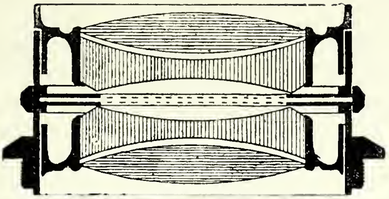
A rectilinear of good quality can be used in conjunction with a telephoto attachment, and satisfactory results will be obtained. This is a test of its quality, as every magnification by means of the attachment necessitates a corresponding multiplication of the errors left in the original lens.

(6) THE UNSYMMETRICAL ANASTIGMAT (figure 97).

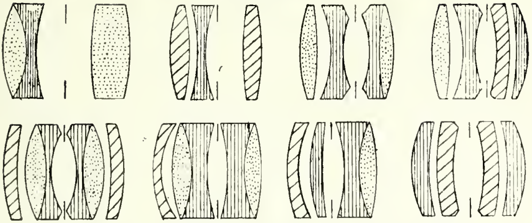
Unsymmetrical and universal anastigmats.

Some considerable difficulty has been found in dealing with the anastigmatic type of photographic lenses, and it has been necessary to divide them into two groups or headings, the "unsymmetrical" anastigmats, and the "universal" anastigmats. Under the former, it is intended to include all those, which could not be considered, for argument's sake, as the

Unsymmetrical anastigmat.



The Unifocal



Unsymmetrical Anastigmats. Figure 97.

logical outcome of the rectilinear lens, that is, lenses which are not composed of two similar cemented combinations without air spaces. The majority of lenses included under this heading are unsymmetrical, in point of fact, that is, the two components are dissimilar in construction and function, and cannot, except in rare cases, be used as single lenses. There are some which possess two combinations of somewhat similar construction, but the lens must be used as a whole to produce a perfect image. Anastigmats of this type cannot be regarded as universal, as they will not allow of their single combinations being used alone, neither do they as a rule cover as large an angle so perfectly as the next type—that is, the circle of illumination is not so large focus for focus.

Figures 98* and 99* tell the photographer at a glance that he is rapidly nearing perfection, and show in what way these lenses are a marked advance over other existing forms. The only correction that is at all at fault is that for flare, which is due to the large number of air

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* Figures 98 and 99 should be compared with the corresponding diagrams of corrections and properties of the other types, for purposes of estimating the merits of each.

Diagram of corrections and properties.

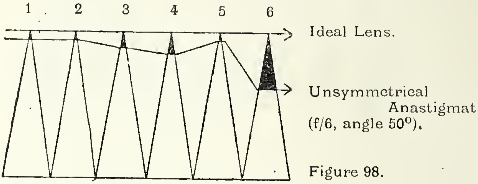

Figure 98.

1. Chromatic aberration.
2. Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

COMPARATIVE DIAGRAM OF CORRECTIONS :—The height of the intermediate line marks the degree to which the errors are corrected; the less "black" that appears, the less room for improvement.

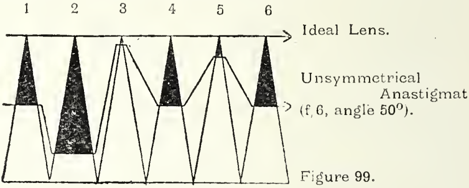

Figure 99.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

COMPARATIVE DIAGRAM OF CORRECTIONS :—The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by the absence of "black."

Simplicity of some unsymmetrical anastigmats.

surfaces, usually highly curved, found in this type of lens. Its properties show us that a high standard of rapidity is reached,but that in consequence, depth of definition at full aperture has been sacrificed; angle of view shows little room for improvement, but the lens as a whole is magnificent. This lens has become more and more popular of late years, for it contains fewer constituent elements than its more perfect rival, the universal anastigmat, while its other properties are sufficiently good for almost all purposes. It can be used for portraiture on account of its rapidity, though its corrections are so perfect that some prefer a softer definition.

H. Dennis Taylor, J. H. Dallmeyer, Ltd.

The unsymmetrical anastigmats can hardly be left without some reference to their ivnentors. These lenses are evidence of marked originality involving means of overcoming the usual errors, previously unthought of, and show a return to lenses of a more simple construction, two of the earliest and better known forms originated in this country being the work of H. Dennis Taylor and J. H. Dallmeyer, Ltd., respectively.

(7) The Universal Orthostigmat (Anastigmat), (figures 100-102).

Universal anastigmats.

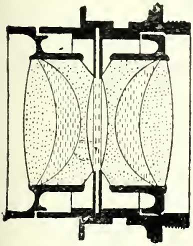
Figure 100.

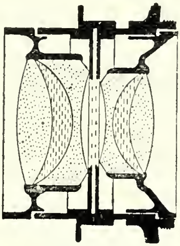
Figure 101.

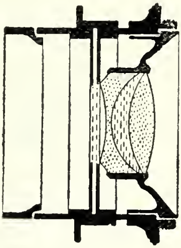
Figure 102.

The lenses included in this heading have almost reached the limit of perfection at present attainable, and will probably not be greatly improved for some time to come. They possess in the highest degree those qualities which are of importance, and although in photographic lenses it is impossible to correct to an equal extent the conflicting errors, yet the nearest approach to complete correction has here been reached.

This class of lens is the best for ordinary photography, and is also used for many branches of special research, such as—

Low-power micro-photography.
Three-colour work.
Enlarging and reducing.
Portraiture (groups).
Telephotography.
Architectural work.
The most rapid instantaneous work.

Branches of work that the universal orthostigmat is suitable for.

Figures 103[*] and 104[*] indicate this more clearly.

Diagram of corrections.

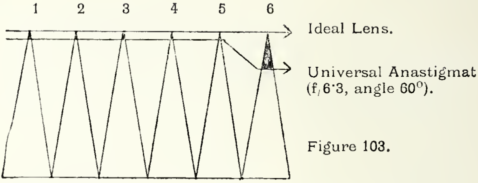

Figure 103.

1. Chromatic aberration.
2. Spherical aberration.
3. Astigmatism.
4. Curvature of field.
5. Distortion.
6. Flare.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree to which the errors are corrected ; the less "black" that appears, the less room for improvement.

Diagram of properties.

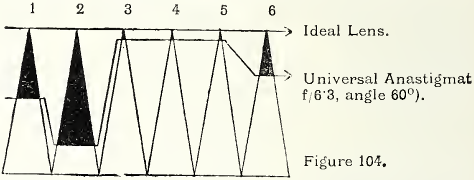

Figure 104.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Ang'e of view.
5. Equality of illumination.
6. Absorption.

Comparative Diagram of Corrections :—The height of the intermediate line marks the degree of the properties referred to. The possession of any property is marked by the absence of "black."

It is the nearest approach to a universal lens, but apart from its uses as a whole, its single combinations form excellent landscape lenses of about double the usual focal length, and are beautiful portrait lenses if used at their full aperture, their field being flat and their definition uniform but not too marked.

The equality of illumination with this type is excellent, even at full aperture, the combinations are very close together, and are usually so large that on a moderate sized plate the edge will receive practically the same amount of light as the centre, except at their full aperture. This closeness of the combinations must be remembered, as in the small sizes up to 4 inches it is barely 5/100 inches, and there is only just room to get the iris in between, let alone a shutter of the "between the lens type." The photographer should be chary of sending a lens of this type to any but a qualified lens maker, in order to have a shutter fitted, as any increase of separation will spoil the covering power.

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[*] Figures 103 and 104 should be compared with the corresponding diagrams of corrections and properties of the other types for purposes of estimating the merits of each.

There is always a fascination in possessing the best of anything, and although there are differences between those made by different manufacturers, the best specimens of the type are pre-eminent over all other forms.

TELEPHOTO ATTACHMENT (figure 105).

Telephoto attachment.

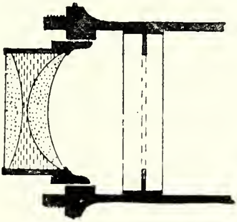

Figure 105.

It is necessary to refer to this lens here as it is of a type which is increasing in importance, and which is opening up a new branch of work possessing possibilities little dreamt of a short time ago. It is in many ways unique. It cannot, when used alone, form a real image (see Section I., page 15): it must be used in combination with a positive of the ordinary kind. A negative lens of this kind should be corrected in the same manner as those already referred to. It is impossible to treat of its special characteristics in a brief *resumé,* and a chapter in Section VII. has been set apart for its full consideration, framed upon a pamphlet,* which has already passed through four editions.

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* "Practical Notes on Telephotography," R. & J. Beck, Ltd., price 6d., bound (50 pages illustrated); unbound, post-free, 1d.

A BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION V.

(1) There are six general types of lenses in use.

- (1) The single non-achromatic.
- (2) The double meniscus.
- (3) The single achromatic.
- (4) The rapid rectilinear.
- (5) The Petzval portrait.
- (6) The unsymmetrical anastigmat.
- (7) The universal anastigmat.

(2) The single non-achromatic lens is one that does not rank as a lens for serious work.

(3) Its chief use is as a supplementary lens for altering the focus of those that are better corrected.

(4) The single non-achromatic lens has a chemical focus.

(5) The double meniscus lens has also a chemical focus.

(6) This lens gives a rectilinear image, i.e., no distortion.

(7) The single achromatic is corrected for colour, but gives distortion at the edge of the field.

(8) The single achromatic is an excellent lens for landscapes, at an aperture of f/11 or f/16.

(9) This lens was the first in which there was any attempt made to correct for colour.

(10) It gives a brilliant picture over a small angle.

(11) The portrait lens is made essentially for speed, and is of little use outside the studio.

(12) It is prone to flare, gives only a small area of critical definition, and a very curved field.

(13) The extra-rapid rectilinear is superseding the Petzval lens for the better class of portrait work.

(14) The rapid rectilinear is the most widely used of all types.

(15) It surpasses the single achromatic in that it is more rapid, gives a flatter field, a rectilinear image. and better definition.

(16) It is an excellent lens provided it is made by a good maker.

(17) The chief difference between these lenses and the anastigmats is that the former are corrected for astigmatism and oblique aberration, only over a limited angle.

(18) There are two types of anastigmats.

(a) The unsymmetrical, with combinations which cannot be used separately, and which have numerous air spaces.

(b) The universal anastigmats, which allow of their combinations being used separately, and cover, focus for focus, a larger angle than the unsymmetricals.

(19) They are an advance on the rectilinears in that they are corrected for astigmatism and oblique aberrations over a very large angle, and can be used over this angle at full aperture without loss of definition. They are also more rapid, giving more critical definition and more even illumination.

(20) They are the best of all lenses for any branch of work, and should always be used in preference to other kinds where their price is not prohibitive.

(21) The telephoto is a negative lens, and does not give a real image (see Section VII.).

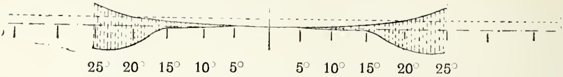


Figure 106.—*Narrow-Angle Single View Lens.* f/*11.*

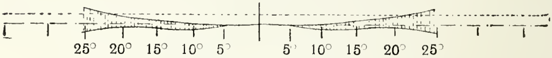


Figure 107.—*Wide-Angle Single View Lens.* f/*11.*

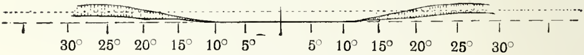


Figure 108.—*Double Meniscus Lens.* f/*16.*

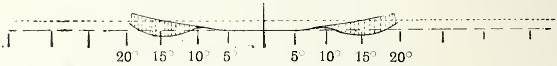


Figure 109.—*Petzval Portrait Lens.* f/*4.*

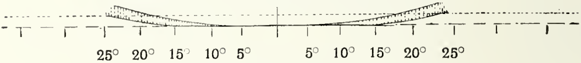


Figure 110.—*Extra Rapid Rectilinear Lens.* f/*4.*

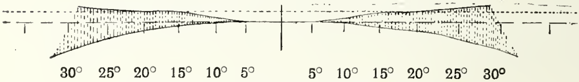


Figure 111.—*Inferior Rapid Rectilinear.* f/*8.*

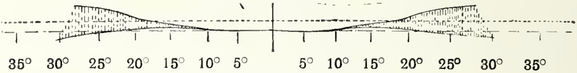


Figure 112.—*Good Rapid Rectilinear.* f/*8.*

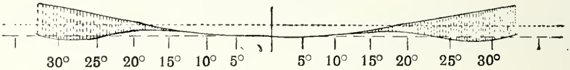


Figure 113.—*Biplanat.* f/*5·8.*

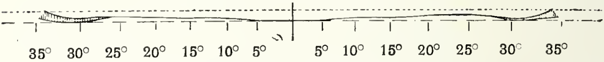


Figure 114.—*Beck-Steinheil "Orthostigmat."* f/*6·3. Series I.*

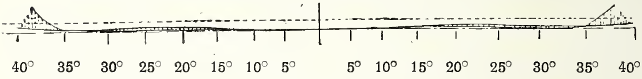


Figure 115.—*Beck-Steinheil "Orthostigmat."* f/*6·3. Series II. Convertible.*

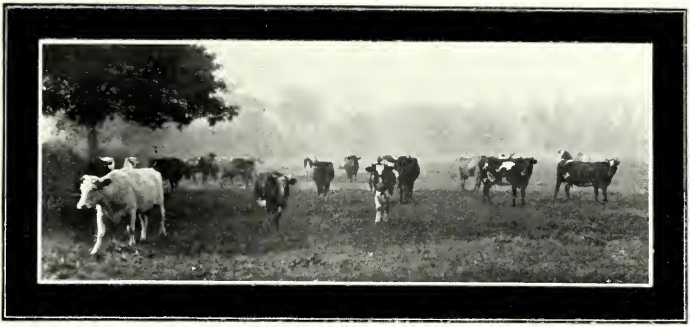
ASTIGMATISM DIAGRAMS of a series of lenses of the same focus to illustrate types. The horizontal line shows the position of the flat plate. The horizontal fine dotted line shows the distance from the plate which the focus may be, without spoiling the definition. The two curved lines are the positions [in all cases by actual tests taken from individual lenses] of the focus for horizontal and vertical lines respectively [Radial and Tangential astigmatic focal lines] over the field covered by the lens. The shaded portions show the astigmatism. A mean position between the two lines indicates the curvature of field.

N.B.—The tests were made on a series of lenses not selected in any way, and may be taken as being representative, although slight variations may be expected in individual lenses.

See page 184.

PLATE XXIX.

AN ENGLISH MORNING.

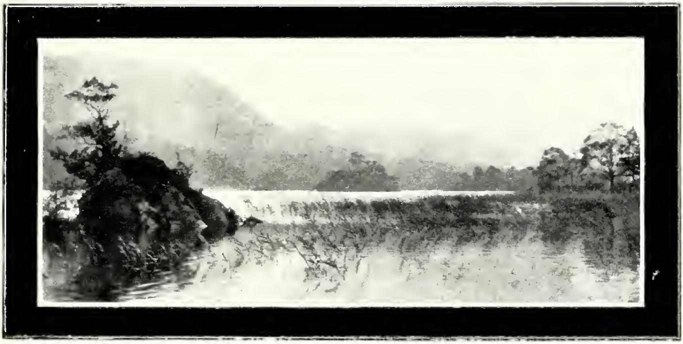


Negative by *H. Andrews.*

From a photograph taken with a Beck Rectilinear double meniscus in a Frena "Max."

PLATE XXX.

RYDAL WATER.



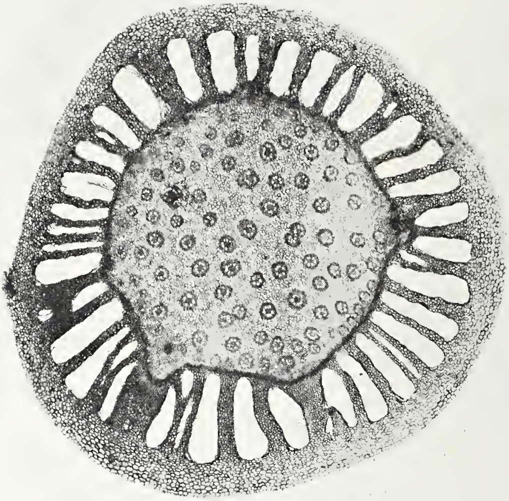
Negative by *H. Andrews.*

From a photograph taken with a Single View Lens in a No. 22 Frena.

See page 214.

PLATE XXXI

MICRO-PHOTOGRAPH OF JUNCUS LAMPROCARPUS.



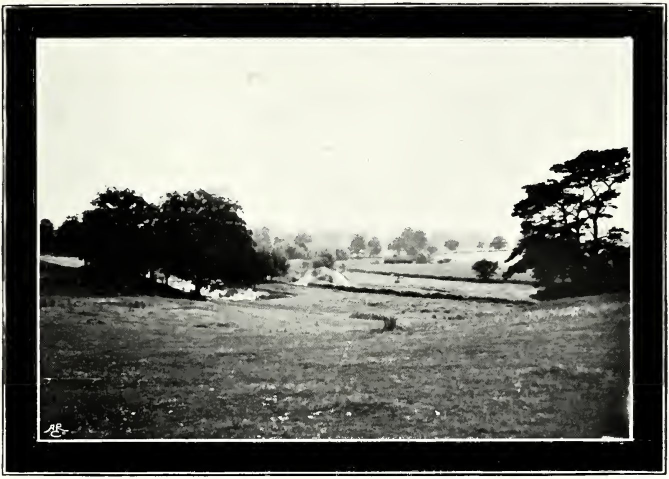
Negative by *Dr. E. J. Spitta.*

From a photograph taken with a 1-inch Beck-Steinheil Orthostigmat, f/5·3. Magnification 20 times.

PHOTOGRAPHIC LENSES.

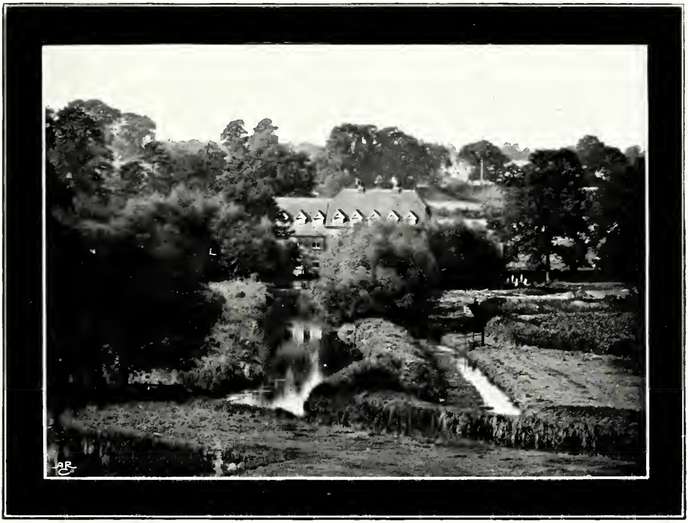
See page 235.

PLATE XXXII.—OLD MILL, ST. ALBANS.



Negative by *H. Andrews.*
From a photograph taken with a Beck-Steinheil Orthostigmat No. 5, $7\frac{1}{8}$-inch focus.

PLATE XXXIII.—OLD MILL, ST. ALBANS.

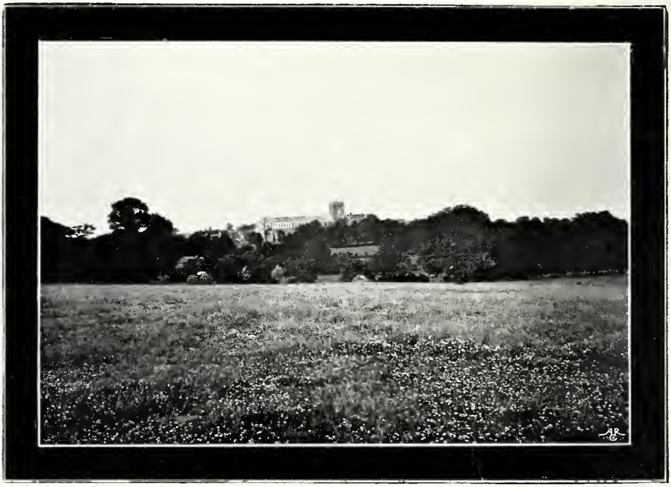


Nagative by *H. Andrews.*
A telephotograph from the same position as the above, obtained by the addition of a low power Beck-Steinheil Telephoto Attachment. Magnification $5\frac{1}{2}$ times.

See page 236 & 239.

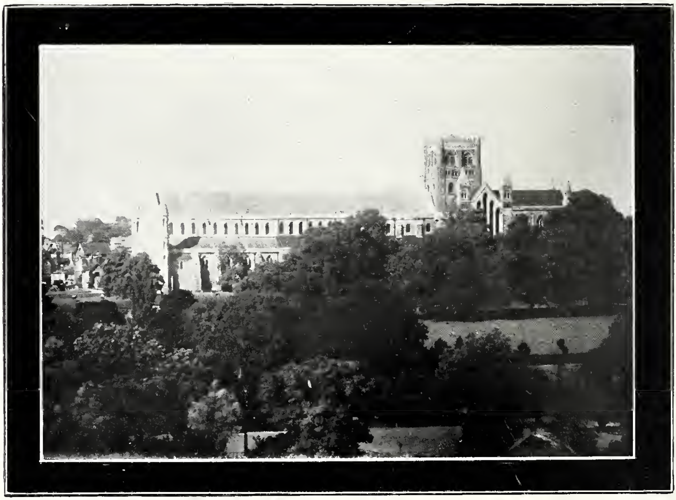
PLATE XXXIV.

ST. ALBANS ABBEY FROM VERULAM WOODS.



Negative by *H. Andrews.*
From a photograph taken with a No. 5 Beck-Steinheil Orthostigmat, 7⅛-inch focus, f/6·3.

PLATE XXXV.



Negative by *H. Andrews.*
The same subject photographed with the same lens from the same spot, with the addition of a Beck-Steinheil low power Telephoto Attachment. Magnification 5 times.

SECTION VI.

PRACTICAL APPLICATIONS.

The early portions of this work dealt with the lens taken as a whole, its properties were discussed and explained, after which the various "types" were described. This arrangement was adopted in order that the most suitable lens for any particular work might be readily recognised—or that the limitations of any lens actually in the hands of the photographer, might be gauged. In order to render the discussion complete, the applications themselves will be considered in this section in their connection with the most suitable lenses. The following branches of work will be treated of in so far as they are influenced by the choice and use of the lens.

Practical applications.

Portraiture.
Landscape and general photography.
Architecture.
Instantaneous and hand-camera work.
Enlarging and copying.
Photo-mechanical reproduction.

PORTRAITURE.

Portraiture, its difficulties.

To the photographic beginner visions will arise of portraits taken of his friends possessing the power of a Rembrandt or the charm of a Gainsborough, and what wonder then, if his first impulse is to plunge headlong into this difficult branch of work? But the experienced photographer, hardened to the fluctuations of light and shade, halation and swing backs—will advise him to be cautious in approaching even a second best friend, lest the latter turn and rend him; for he knows the pitfalls which surround the ardent beginner, and he also knows how difficult it is without special accessories to produce anything better than a caricature. Portraiture more than any other branch of work calls for special apparatus and lenses. It is true that a fine portrait can be taken with a common lens. It is difficult, but it can be done; a machine or instrument of any sort is not so important as the person behind it, but the beginner who is going to take up portraiture seriously cannot afford the time to learn to use a bad instrument—life is too short—a proper choice of lens will greatly help towards success. With an unsuitable lens even the experienced professional, who has all the advantages of lighting, backgrounds, accessories and costumes, may find difficulty in producing artistic results, and no excuse is required for entering somewhat fully into the subject.

Primary considerations.

Primary considerations:—

(1) Focal length.
(2) Rapidity.
(3) Definition.

Focal length.

(1) Focal length:—Whatever the type of lens that is employed, its focal length is a matter of great importance; upon it depends the truthful rendering of the different portions of the sitter and much of the correctness of the modelling. In dealing with photographs of the head and shoulders, a total distance of some 8 or 9 inches in depth will have to be almost equally defined. The nostrils, eyes, ears, and back of the head have almost the same relative importance, and should be

rendered with a similar degree of distinctness, though a trifle more brilliancy in the eye is desirable. The shoulders and chest are only of secondary importance, and less depends upon them in depicting the characteristics of the sitter; they are accessories, and in order not to detract from the main interest, should be rendered with a less degree of definition.

Quality of definition.

The fact that the main aim of all photography, which is not undertaken for purely diagrammatic purposes, is to portray on a flat surface an object which possesses length, breadth, and thickness, should never be forgotten; and the quality of the definition in the various planes of the picture can be made to play an important part in producing an appearance of solidarity. The eye, attracted first by the sharpest area of definition, may roam over the whole photograph, but will return again and again to the clearest part. If the whole is evenly defined there will be no rest for the eye, and the interest, which, but for the fact that all is sharp, might have been riveted upon some salient feature, will be dissipated. Comparison between the "regulation" vignetted bust of some years back and a photograph by a modern artistic worker will emphasize the point. In the former case, whether it be the carefully arranged curl on the forehead of the sitter or the fifth waistcoat button, the definition will be so equal and brilliant throughout that one is tempted to think that the photograph is intended for a fashion plate to show the latest cut of waistcoat or the newest method of hairdressing. At best the result will be but a travesty, and destroy all traces of personality. Now, consider a second photograph, that of a man past the prime of life, with iron-grey hair and furrowed brow; notice the gleam of light on the hair, the softly marked wrinkles telling of a life almost lived out. These have not been carefully removed

Portrait of an old man.

by the soulless retoucher; the shoulders are softly defined, sufficiently so to suggest the stoop, while the-old-fashioned stock, hardly discernable, forms a mere accessory to complete the picture. The quality of definition is soft yet equal over the different planes of the head, the nose and chin are not unduly large, or the forehead dwarfed by the use of a short focus lens (plate XX.*).

Short focus lenses, in portraiture.

A short focus lens possesses the quality known as depth of definition to such a degree that it might, at first sight, be thought to be useful to the portrait photographer, but it entails exaggerated perspective which renders its employment unsuitable. Where it is employed distortion results—the sitter's nose will appear too large and the ears and forehead dwarfed, sometimes to such an extent as to make the likeness ridiculous. Reference to figure 116 will explain the reason for the distortion.

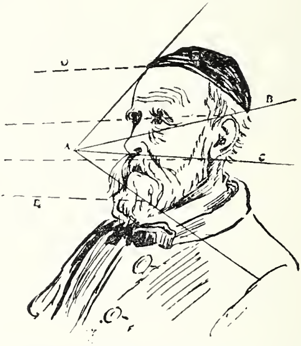


Figure 116.

It has been explained that the shorter the focus of the lens employed the nearer the camera the object must be to produce a picture of a pre-determined size. Suppose the lens A is of so short a focus that the sitter must be placed in the position shown in the diagram

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*In the Edition de Luxe, this plate is reproduced as a photogravure frontispiece. This edition, beautifully bound, price 3/6 post free.

(figure 116). The ear will be photographed the same size as the end of the nose or half its correct size, because it is nearly *double* as far away. The lines in the diagram indicate the direction of the rays of light, all objects included in any cone as A B C will be photographed the same size. Similarly the height from the chin to the brow will be represented by this lens as nearly double that of the back of the head, and the sitter will appear to have no cerebellum. When a lens, having a long focus relative to the size of the picture, is used, it will have to be placed much further from the object, and lines drawn from different portions of the sitter will now be represented by the lines D E, etc. In this case they will not converge so rapidly, and the front of the sitter's head will be included in only a slightly larger cone than the back. The ear will subtend a greater angle than the end of the nose, and the various portions will have their true relative value.

As long a focus lens as the studio will permit should invariably be used. A good length is three times the longest side of the plate in use.

Suitable foci for portraiture.

For C.-D.-V. work - -	7 to 9½ in.
For Cabinet - - -	14 to 18 in.
For Promenade - -	20 to 26 in.
For Panel - - -	27 to 35 in.

The above figures are, of course, only approximate, and can be varied to a considerable extent. The scale on which the sitter is to be reproduced will vary according to whether it is to be a full-length study, three-quarters or bust, and it is more particularly for the latter work that the above foci should be employed. It will be only those favoured with long studios who can employ the lengths of focus therein recommended, and the focus used may be reduced to double the longest side of the plate to be covered, without introducing serious distortion.

The length of studio required for the use of different focus lenses is appended in the form of a table.

Table of studio lengths.

Focus of Lens.	Size.	Kind of Portrait.	Length of Studio.	Distance of lens from object.	Typical Lenses.
In.*			feet	feet	
6	Carte-de-Visite	Full length	18-20	11-12	No. 2 Biplanat No. 4 Beck-Steinheil*
7½	Carte-de-Visite	Full length	22-25	14-15	No. 3 Biplanat No. 5 Beck-Steinheil*
8½	Carte-de-Visite	Full length Bust	24-28 10-15	17-19 5	No. 4 Biplanat No. 6 Beck-Steinheil*
9½	Cabinet and 5 × 4 Groups	Full length Bust	20-23 12-17	12-13 7	No. 5 Biplanat No. 7 Beck-Steinheil*
11	Cabinet and ½-pl. Groups	Full length Bust	25-30 13-20	17-18 8	No. 6 Biplanat No. 8 Beck-Steinheil*
14½	Cabinet, Promenade & 1/1-pl. Groups	Full length Bust	32-40 14-20	23-24 7	No. 7 Biplanat No. 9 Beck-Steinheil*
19	12 × 10 Portraits of Groups ...	Full length Bust	20-25 14-20	13 7	No. 8 Biplanat No. 10 Beck-Steinheil*
24	16 × 12 Ditto ...	Full length Bust	25-30 14-20	14 8	No. 9 Biplanat No. 11 Beck-Steinheil*

* The Beck-Steinheil Orthostigmat is more particularly suitable for group work. The Biplanat for both equally. The half combination of a Beck-Steinheil Orthostigmat makes a first-rate portrait lens for large heads.

In the above table it will be noticed that room is allowed for the camera, operator, etc., of from 6 ft. to 8 ft., and should the photographer know from his experience that this is insufficient, more should be added to the suggested studio lengths. The employment of extra-long focus lenses for large size pictures entails certain disadvantages which must be mentioned. These lenses are large and heavy, and difficult to carry about, while the camera must of necessity have a long extension. The price will also be high. Of recent years there has been an increasing enquiry for cheaper long focus lenses giving softer definition (see plate XXI.) than the old Petzval type of portrait lens, and the half combinations of such lenses as the Beck-Steinheil Orthostigmat or the

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*This length of focus is approximately that which is in general use.

Biplanat (see plate XX.*), while only half the price of the whole, will double the available focal length, be somewhat lighter, and give excellent results for artistic work.

Critical and soft definition.

This type of lens has such distinctive features that two portraits are here illustrated. Plate XXII. is a portrait taken with an 11-inch Biplanat as a whole at f/8, and illustrates in an effective manner two points of importance. The lens was of far too short a focus for the cabinet size picture, particularly as the sitter has her head thrown back, showing rather prominently, the end of the nose. This is made unduly large, as also is the mouth—in fact as a picture, the result is poor. The definition is much too critical for the subject, a young face is not sufficiently pronounced in character to warrant anything but soft delineation—the bloom of youth cannot be represented by microscopic definition. In plate XXIII. the same sitter is photographed under similar conditions of lighting, but with the half combination of the same lens, a 22-inch single lens with an aperture of about f/9. This result illustrates the antithesis of the foregoing, the features resume their normal relation, for the focus is now three times the length of the longest side of the plate and the definition is pleasing, being perfectly even over the whole of the face, and just sufficiently soft over the shoulders to give a gentle contrast.

Limitations of the single lens for portraiture.

From these two illustrations the value of a single lens for portrait work will be appreciated, and one may expect a steady increase in its popularity. In the examples cited the cost of the lens giving the best result, was only slightly more than half the other; a Petzval lens of the same focus as the single lens would cost a prohibitive sum. There are, of course, limitations to the use of a single lens. Where rapidity is of primary importance, these lenses are unsuitable, as, given sufficiently good corrections, they cannot be made so rapid as a doublet.

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*This plate appears as a photogravure frontispiece in the Edition de Luxe.

(2) RAPIDITY.

Rapidity in portraiture.

The experience of generations of professional and amateur workers in portraiture has demonstrated the fact, that rapidity is often an essential for successful work in this branch. It is possible under favourable conditions to produce first-class results with a slow lens.* But the conditions under which portraits are procured are generally such that advantage must be taken of every ray of light that can be included by the lens. Except for group work, which will not be here referred to, all negatives will be produced indoors in a studio with a northern light, and most of that cut off by blinds for purposes of modelling. Some of the finest artistic effects are obtained by using light coming from one source only, perhaps from an area of not more than 6 square feet.

Effect of illumination upon modelling.

The modelling of the subject will largely depend on the handling of the light. If a sphere be placed in a room, brilliantly lighted upon all sides, it will appear flat like a disc, but gradually cut off the light on one side and the effect of curvature will begin to appear, the modelling will improve, till it will be at its maximum when the strongest light comes from but one side, and there is just sufficient reflected light from the walls and ceiling to moderate the shadows. The peculiar effect of lighting generally spoken of as after Rembrandt (how that venerable gentleman must turn in his grave at the mere thought of some of the results—by his commercial pupils) is produced by lighting the subject from one well-defined source, say an opening 3 ft. square

After Rembrandt.

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* In treating of the various applications to which lenses may be put, the most suitable lenses only are indicated, not those which could be made, under certain conditions, to perform the work.

Lighting for the Rembrandt effect.

high up in the studio side light, and placing the camera nearly opposite to the source of light with the sitter between the light and the lens. This is the class of portrait to severely test the rapidity of a lens; there will be high light running down the profile touching the neck and some part of the hair, while the majority of the sitter will be in shadow—shadow that must not be too opaque lest the result be a silhouette, but clear and transparent and full of detail.

Comparison of outdoor and indoor photography.

Out of doors a portrait of small size can be taken with an exposure of 1-80 of a second, at f/8 in a bright light. In a studio the light will be cut down, and moreover, the sitter will be moderately near to the lens, so that the light affecting the photographic plate will perhaps be but 1-500 the intensity of that outside. Now, the photographer is called upon to produce pictures of children and other restless creatures, so that short exposures must be given, for who can follow the working of the infantile mind and discover the psychic moment when stillness of face and limb are coincident, and will continue so for a second or more? It is not with children alone that short exposures are the order of the day. Adults also are subject to attacks of the fidgets, and the photographer who was obliged to wait for stillness of the subject, combined with a satisfactory expression, could accommodate but a small number of sitters in a day. If the photographer is accustomed in the ordinary way to use rapid plates, the only method of further reducing the exposure is by the use of a rapid lens. A lens working at f/4 is eight times as rapid as one working at f/11, and an exposure of $\frac{1}{8}$ sec. is correct for the f/4 lens when 1 sec. would be necessary for the other.

Fictitious rapidity.

There is a point, however, to be considered—if a lens working at an aperture of f/4 is always stopped down to f/8 to insure satisfactory results, it is no more rapid than a lens whose largest aperture is f/8, in fact, there are positive disadvantages pertaining to the rapid lens stopped down. Some photographers, when asked what aperture they use will tell you that they don't know, neither do they know the focus of the lens; they only know what result they want, and they know when they have got it, but the method by which the result is arrived at does not interest them. It may be found that they are using an f/4 lens of the Petzval type stopped down to f/8 or f/11, for which they may have paid, if it be a lens by a first-class maker, some £25 or £30. If they had gone to the trouble of finding out what aperture was the one most suitable for them to use, a lens of this aperture could have been purchased at half or quarter the price.

Daguerreotype.

In the early days of photography, when the Daguerreotype was in vogue, it was necessary to stand some 30 seconds in the blazing sun to procure a picture of any kind, and an increase in the rapidity of the lens must have been a veritable Godsend. Following that, came the wet plate process, still requiring exceptionally long exposures, and the Petzval lens introduced at that period with an aperture passing some 32 times as much light as the lenses then in use, was welcomed as a means of shortening the exposure, and universally adopted. Old customs die hard, and even to-day the Petzval is the most popular portrait lens. It has little claim to be; the field is extremely curved, the definition is critical, too critical and that over a very limited field, after which it falls away rapidly; it is subject to flare, and stopping down does not increase its good qualities to any great extent; it is heavy and costly and only applicable to indoor work – groups and outdoor subjects being alike beyond its scope. Remembering that it is often used at from f/6 to f/8, there must be other lenses more

Why the Petzval lens is still the most widely used.

suitable. Since the wet plate days, the rapidity of their "dry" relations has increased with leaps and bounds, and to-day the fastest plates are some 100 times more rapid than the old wet ones, and there is no need to use a lens entailing so many disadvantages as the Petzval for a slight gain in rapidity.

Aperture for portraiture.

A lens for portraiture should have an available aperture of f/5-6 or thereabouts, at which it can be used without stopping down. A lens of this class, such as the "Biplanat," will do anything a professional photographer may require of it, including groups out of doors—where a fair angle is to be included—and it may be used with a smaller stop for landscapes. On the other hand, where a speciality is made of children's portraits, there is no doubt that a larger aperture is required such as f/4, and this being the case, a lens embracing a larger angle than the Petzval with a flatter field and more even definition should be obtained; a lens of this type is the Extra Rapid Rectilinear.* For adults, a lens as slow as f/11 need not be discarded. For large heads there is no lens to touch the rapid single lens, the definition is delightfully soft and even, and the focus will of necessity be long if it is a half combination of a rapid lens, while the price, a consideration nowadays, will be much less than that of a doublet.† For group work, whether indoors or out, a lens is needed that gives a flat field and even definition; here, again, the Petzval is found wanting, and a lens such as the Biplanat or the Orthostigmat is recommended.

Biplanat.

Extra rapid rectilinear.

(3) QUALITY OF DEFINITION.

Quality of definition.

Quality of definition can be fairly considered as of primary importance in portrait work. The days of Daguerre have passed, and with them the necessity of placing the subject in

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*For further points on this lens, compare figures 109 & 110, page 160.

†See plates XX., XXI., XXII., and XXIII.

Critical definition.

the full glare of the noonday sun in order to reduce the necessary exposure. When this had to be done the lighting was beyond control; there was no modelling, and all that was wanted was definition; critical, diagrammatic definition. As plates became faster and the lighting could be controlled, critical definition still held sway, although Dallmeyer introduced a form of the Petzval lens in which the requisite softness could be obtained by unscrewing one element of the back combination.

Advantages of softness of definition.

Latterly it has been shown that lenses can be made having the advantages of rapidity and flatness of field, together with a softer definition, while more brilliant definition can be procured by slightly stopping down. Examine any portrait by a great, or indeed a less known painter, and where will you see every hair in the eyebrow clear and distinct, and every thread in the necktie or dress so plainly depicted, as to suggest a Manchester merchant's sample? It may be necessary for a "Photographer by appointment to the Police" to present a cabinet portrait to his employers in which every hair is depicted—for purposes of identification—but this comes within the scope of copying rather than portraiture. Soft definition is essential for truthful work. This may be obtained by placing the lens slightly out of focus or by allowing the presence of a small amount of spherical aberration, but such an error must not be present in too marked a degree or the picture will tend to show doubled lines at the edge of any white portion, such as the collar, and the examination of such a picture might suggest the idea that one has dined "not wisely but too well."

Biplanat for portraiture.

A lens such as the Biplanat, which in the longer focus models possesses a certain amount of softness in the centre of the field with the largest stops, is very suitable for portraiture, particularly for amateurs, as the negatives produced by it require less retouching.

Retouching.

It is generally supposed by the artistic public, that retouching is the worst evil that can befall a professional portrait, and there is a basis of truth in the idea. To retouch a photograph so that the skin appears to have a silken texture, and to remove all characteristic lines ruins it as a likeness, and should not be tolerated except in the portraits of professional beauties. Some retouching, however, will be necessary in almost all large portraits. A photograph will translate a slight yellowish mark or freckle into a black disfigurement, and the work would be quite untrue to nature unless such a defect were removed. Curious devices have from time to time been invented to attempt to soften down the result. One method was suggested in which a gridiron with a number of small gas flames was waved between the sitter and the lens during a portion of the exposure, but the only effect of this, was to somewhat fog the plate, a matter which might have been accomplished in a much simpler manner.

Secondary considerations.

There are two secondary considerations to be mentioned :—

(1) Angle of view.
(2) Curvature of field.

Angle of view.

(1) Angle of view :—This is much the same question as that of the most suitable focus, although technically it means the angle of view which each lens is capable of including, apart from the angle it actually subtends when used on a particular plate. A limited angle of view is all that is required, for if the lens has an equivalent focal length equal to three times the longest side of the plate, this will only mean an angle of some 20° at the most, and almost any lens having a focal length of 12 inches, will illuminate a ¼-plate at full aperture. If groups are to be taken, a greater

angle may be necessary, and under certain circumstances, it may be as much as 40 or 50 degrees. This will mean that the focus of the lens will have to possess equal illumination over a larger angle than is usual in lenses of the Petzval type. Any good lens of the Rapid Rectilinear Biplanat, or Anastigmatic type, will answer well for this work, but by preference choose a lens with an aperture of f/6, so that short exposures may be given in bad light.

Rapidity for groups.

Quick exposures are more essential in a large group than for single figures, for there are many individuals who may move. With the most restless single sitter a period of stillness may, with patience, be caught, but with a number of people these periods of rest will not coincide.

Curvature of field.

(2) Curvature of field:—It has been said that a certain amount of saucer-shaped curvature of field is useful, in that it requires, that a grouped series of figures should be so arranged that the members at the edge are nearer to the camera than those in the centre, in other words, that the group form a semi-circle. It is doubtful if any excuse can be found for such a statement, the arrangement is unnatural and unpleasing, and the figures at the edge will come out larger in size than the centre ones. On the other hand, a stiff row of people is not artistic in a photograph, or for that matter, anywhere—for group work a lens with a flat field is undoubtedly the best. If the lens were to have a field curved slightly away from the lens the figures at the edge would require to be somewhat further away than the central ones, which is the more suitable arrangement, giving as it does more prominence to the centre of the picture—but this form of curvature is seldom met with in anything but experimental lenses.

For busts curvature of the field is of little importance, for the head is usually near the centre of the field, and if the accessories be slightly out of focus it only enhances the effect.

Portraiture without accessories.

Before leaving the question of portraiture a few general remarks may be of interest. A large number of amateur photographers have cameras of the box model type, and to these, the desire to do some portrait work, is sure to come sooner or later. It may be that their cameras are possessed of a certain amount of focussing motion, but it will rarely be enough to allow of a large sized picture of a head being sharply focussed on the plane of the plate. It is not advisable to stop down to get the extra depth required, as it would mean that the background would be equally sharp and the picture flat. An example in point is given in plate XXIV. The picture was taken in Boulogne, when two methods were possible; the first method would have been to stop down the lens, as mentioned, till everything was sharp; this result would have been anything but pleasing; the picture obtained was gained through the instrumentality of a supplementary lens, which is the best method of effecting a successful portrait or genre study with a box model camera. It so shortens the focus that only objects at a specified distance are rendered sharply, the rest being somewhat indistinct; it also enables objects as near to the camera as 2 ft. to be sharply focussed, so that full-sized portraits can be taken.

Magnifiers for portraiture.

The question of supplementary lenses or magnifiers is more fully described in Section VI. One advantage this system has for hand-camera portraiture, is that the actual depth of definition of the combined lens and magnifier is engraved on the supplementary lens, so that the range of focus at any one time is known, and the position at which the sitter is to be placed determined with accuracy.

The question of lighting is of too technical a

Lighting.

character to be fully discussed here, but for the benefit of those who do not possess a studio a remark or two may serve as an indication of the lines upon which to work. The chief light should come from one side to ensure the requisite modelling, while there must be sufficient from the other to illuminate the shadows. The chief light should come from above, but never so much so as to pour straight down upon the sitter's head, or it will give dark shadows under the eyes and nose and a blazing light on the forehead and hair. A good portrait can often be obtained under a veranda with light from white clouds coming from one side, a white screen being placed on the other and a sheet upon the ground. The camera should always be a little above the sitter's head, so as not to over emphasize the chin and neck or give an unpleasant view of the nostrils. Avoid the brick wall, or the laurel as a background; blankets and curtains slightly out of focus, or a plain plastered or distempered wall are very fair substitutes for the more elaborate accessories of the professional.

Diagram of most suitable lens.

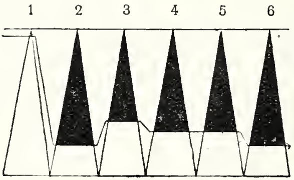

Figure 117[*].

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required; the less "black" that appears, the less of that particular quality is essential.

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[*] This diagram illustrates the degree to which the various qualities indicated are required for a good portrait lens; those that have been described as of primary importance must be satisfied first, and those of secondary importance next.

If on comparing this diagram with those descriptive of properties, occurring in section V., it be found that several types possess the six properties to a greater degree than indicated in fig. 117, it should be remembered that it does not prevent their making good portrait lenses.

For the purposes of comparison a diagram (figure 117) is attached, which illustrates the relative importance of the qualities for this particular branch of work, and if the diagrams in the previous Section V. are referred to, the type of lens which most nearly approximates to this diagram in its essentials is the one that is most suitable. It must be understood that cut and dried diagrams like this cannot be quite accurate, and are only intended as a guide.

LANDSCAPE AND GENERAL WORK.

Landscape and general work: what is included.

This heading is so wide that it might at first sight appear to include anything and everything that may cross the photographer's path, but there are many branches that do not fall within it, however broad the expression "general" may seem; there is a large field where photography is employed for purely technical purposes. It is used to record the construction of mechanical contrivances, to produce mere transcripts of infinite variety, from a pulpit to a string of pearls. It forms an aid to many studies where it is both more rapid and more exact than pencil or brush work. It has aided in astronomical discoveries to an extent little guessed by the uninitiated, while for the reproduction of pictures it is of the first importance.

Stand-camera work.

Some divisions must be made, however, and this heading is not intended to apply to hand-camera work, but rather to the careful and precise use of the "Stand camera" upon the tripod. Even the amateur who takes up photography as an amusement in his idle moments, will be anxious to obtain as beautiful results as possible, and although the power of appreciating what is, or will make a picture, cannot possibly be pointed out in a book, the influence of the lens upon the artistic qualities of the results is perhaps possible.

Technique.

The "Technique" of photography is not the governing factor of artistic work that some would have it believed, at the same time the painter cannot afford to neglect the consideration of his various pigments or the photographer his lens. The photographer who approaches his subject equipped with a knowledge of the effect of a lens on the resultant picture, will be in a better position to produce good work than one who considers not his tools.

A beautiful landscape.

It may be some help to analyse the manner in which a beautiful landscape impresses itself upon the mind; the effect caused by colour need not be here discussed, as at present it cannot be reproduced in the photograph.* The effects of light and shade will not be referred to, as the lens has but little influence on their production, but the arrangement and relative sizes and importance of the different objects is worthy of attention.

The eye will roam over an expanse of country seeing only a very small portion distinctly. It can range over a number of objects, each of which it will see vividly depicted in succession, but in most cases there will be one feature which chains the attention more completely and to which the other portions are merely subservient. An impression, to be complete, should allow the eye to rest, while the mind can contemplate and form a broad idea, rather than that the eye should flit about among a number of conflicting interests making it impossible to form an idea of the scene as a whole. A pleasing photograph must aim at a similar result, and although the means at the photographer's disposal are limited, there are certain methods of arriving at this end. The arrangement of the view, the choosing and placing of an appropriate figure in the foreground, the selection of the point of view so that some reflection or other brilliant object forms a striking incident, is of great importance, but there are other influences purely optical that have an important bearing on the result. The relative sharpness of the different objects can be varied by judicious use of stop and focussing motion; the most important object must be the sharpest, while the remainder should be rendered in differing degrees of clearness, but not so fuzzy as to cause in the observer an unpleasant feeling in the eyes, for such an extreme may be even more out of place than a too brilliant definition. The thing to be most carefully avoided in landscape work is microscopic delineation over the whole plate, which reduces the most carefully composed subject to the level of a diagram. This is particularly true in hazy England, where nothing but the "glass eye" of the camera sees the distant horizon, even on the brightest days, as a clean cut line.

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*There have been many methods of natural colour photography introduced, but in all cases there is danger of the tone and colour values of nature being misinterpreted, owing to the use of some arbitrarily selected pigment necessary to the reproduction of the various colours.

Relative sharpness.

Fuzzytypes.

Extremes, however, of any kind are bad, and some of the so-called artistic productions are mere "fuzzytypes" without point or interest. It is claimed for the latter that they give a breadth and strength, allowing of a fine play of the imagination, but surely the imagination must have some guide or stimulus to direct it. It is the subtleties of light and shadow, of tone and half-tone that allow of its full play. Let an illustration be taken.

An ideal landscape photograph.

Imagine a dusty moorland road stretching across the high land separating two Yorkshire dales. It winds here and there through a slight depression to the distant hills, not straight like a giant's rule, or like a Roman road, which passes over hill and valley, without a turn or swerve through one county, or another. This one follows the contour of the hills and along it moves a flock of sheep, slowly, guided to market by a solitary horseman and two patient sheep-dogs. The road is dusty and the sun is hot, see how it beats down on the backs of the curly-coated sheep, and touches the stirrup and rein of the rider which forms the interest of the picture. On either hand is the rough moor, while beyond, the white winding road to the farther blue hills across the dale, somewhat indistinct, seen through the dust of the driven sheep. All that is to be seen sharply are the sunny backs of the sheep and the tireless dogs and man; one is just conscious of the moor on either hand and of the endless road and distant hills, of the dust and stones at one's feet. These are but accessories and are only vaguely felt; it is the dumb patience of the flock that rivets the attention. So it is in all the striking scenes of nature and of life, something perfectly clear, forcible, distinct, and much vague, indistinct, forgotten—after it is passed. Now for a moment picture a change. The road nearer becomes clear and sharp, the stones stand clean cut—flint nodules and granite chips—the heather at either side of the track drawn stem for stem, bell for bell, the hills in the distance brought close and clear and sharp, and the flock and its watchers brilliantly pictured in every detail. The picture and its meaning is gone, one's eyes have nowhere to dwell, there is no atmosphere, no illusion, no scope for picturing the wordless story—all is unrest.

The ideal landscape: a change.

This latter description applies to many landscape photographs, the former is an ideal by no means unapproachable.

Suppose, with regard to its qualities for rendering perspective, that the lens is suitable for this class of work. In the majority of cases it will be a long focus lens that is chosen—it is only in rare instances that an exaggerated perspective giving a greater appearance of distance can be used. It is well to have a lens with a large aperture which should be opened to its limit, the principal object being focussed carefully, and the picture examined on the ground glass

Plane to be most sharply rendered.

to see if the planes of the middle distance and distance, are rendered sufficiently softly to differentiate between them, but not so indistinctly as to be lost. Stop down till a point is reached where the eye is satisfied in this respect, but beware of making the distance too sharp, as it is never seen perfectly distinct in nature. The haze usually present in an English landscape can be relied on to subordinate the far distance, and it is the foreground and the middle distance that require to be carefully watched.

Perspective and solidity.

The representation of different planes in a picture in differing degrees of sharpness is one of the best methods, apart from perspective, of indicating solidity. Stereoscopic vision, due to the fact that two distinct images of the same object are received by the two eyes, is the main agency by which distance is estimated and the appearance of depth and solidity obtained by an observer. As a single photograph can never give two separate pictures, one for each eye, other means to produce the same effect must be employed. Variations in sharpness have been alluded to, perspective has been treated of under angle of view, but another word might be said upon the use that can be made of haze, or, as it is sometimes called, atmospheric perspective. As objects become more and more distant the haze due to the minute particles of matter in the air becomes more marked, so that objects at a distance are fainter and less sharply defined. This is liable to be exaggerated unless an isochromatic filter is used, for the haze is peculiarly full, as it were, of actinic light. It will vary according to the weather and the time of day; if the sun is low in the sky, haze will be more apparent. A good test as to the quality of the light in this respect is to examine the shadows; there are certain brilliant days familiar to all, when the shadows, usually grey,

Use of the isochromatic filter.

Test for clearness.

are black and hard; this is a positive indication that haze is absent and usually occurs in this country after a severe rain storm, but it is a condition much more common abroad.

In a Swiss mountain view,* for instance, peaks which are in reality 20 or 30 miles away, appear to be in the next valley, making it difficult to produce Swiss landscape views that appeal to the dweller in this land of half-tones. On the other hand, a view from one of the low hills of Galloway will have upon a clear day, the foot hills of the English Lake District for a horizon, blue and indistinct in the distance. These will be next to impossible to reproduce in a photograph unless by the aid of a spectrum filter.

Lighting also aids solidity, the long shadows of early morning or late evening helping composition ; direct light with no shadows invariably flattens the picture and makes it impossible to get a good gradation of tone.

The foregoing remarks might be out of place when discussing purely instantaneous or hand-camera work, but may, perhaps, be excused on the ground, that, in this branch more than in any other, will be found the thoughtful photographers. The influence of a suitable lens will now be considered.

Primary considerations.

PRIMARY CONSIDERATIONS.

(1) Focus.
(2) Angle of view.

Focus.

(1) Focus :—Can be varied at pleasure between indefinite limits, but it is the question of which focus to choose, that presents difficulties. Let a long focus lens be chosen; as much as twice the longest side of the plate is a good average, including as it does only some 35 degrees. The reason for this choice is the one discussed under Section V., angle of view. A narrow-angle picture can be viewed at any

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*The photogravure included in the Edition de Luxe, illustrates a picture taken at a distance of some seven miles.

distance with truth, a wide or medium-angle one must be viewed at a short distance; a wide-angle picture reduces the importance of the distance and exaggerates the foreground, ponds become lakes and lakes become oceans. This might even be tolerated were it not that the "perspective lines" are so increased that a square becomes oblong and a circle an elipse. Again, a wide-angle lens means one of short focus, and a short focus lens gives too great a depth of focus, rendering all planes in the object equally sharp.

Differences of focus: an extreme comparison.

Plate XXVII. is taken with a 56-inch focus lens upon a $\frac{1}{2}$-plate (a telephoto lens), while plate XXVIII. is taken with a $7\frac{1}{8}$-inch lens. The standpoint from which the two are taken was chosen so as to render the old mill about the same size in both pictures. It is scarcely necessary to point out the differences. In the picture by the shorter focus lens the distance is lost, the mill stream might be the Thames without its shipping, and the composition is spoilt through having to take the picture from too close a position—though the clouds almost save the picture. It is unnecessary to use as long a focus lens as that which was used in plate XXI., for a subject was chosen that required a very long focus lens to emphasize the point, but as often as not a poor picture with a 7-inch lens will become a good one if the lens is changed for a 12-inch one. In this particular case nothing short of 30 inches would have done, as to get the distance properly rendered a position had to be taken up on a slight hill some half mile from the mill, because any nearer point would have been too low.

Lenses with more than one foci.

With a stand camera the use of a lens of about 12-inch focus entails little difficulty. More than one focus is required for serious landscape work, and no lens is more convenient than the "Convertible" Orthostigmat (anastigmat). A half-plate lens of 7¾-inch focus* may be used for snap-shots, interiors, street subjects and architectural work, while its two elements form single lenses each having a focus particularly suitable for pictorial landscapes; but the above remarks should not prevent the possessor of a hand camera from attempting landscape work of an artistic kind.

Plates XXIX. and XXX. are inserted, not that they claim to possess the stamp of genius, but that they are pleasing and have certain qualities of light and shade, depth and solidity. In both cases the effect of distance is given by the lack of absolute sharpness and the full use of the blue haze of our English landscapes. The long shadows from the low sun, lying across the meadow in plate XXIX., assist the composition.

Angle of view.

(2) Angle of view:—This is closely allied to the foregoing, but for purposes of comparison it is convenient to consider it separately. The focus of a lens, compared with the plate upon which it is used, determines the angle of view of that picture, but the angle of view of the lens means that it is capable of giving when used upon a large plate. A narrow-angle lens of 12-inch focus and a wide-angle one of the same focus will give identical results upon a ¼-plate, but whereas the wide angle might be used to take a 15×12 picture, the narrow angle, if used on the same plate, would only illuminate a small portion of the centre, leaving the edges black.

Measuring of angle of view.

A fairly wide-angle lens is a distinct advantage, as although the whole angle is not utilized at one time on a large plate, the lens can, if necessary, be placed considerably out of centre by means of the rising front, and any portion of this large angle selected; while a narrow-angle lens will not allow of an extended use of the rising front. Moreover, a wide-angle lens of a considerable focus, used instead of a narrow-angle lens on a $\frac{1}{4}$-plate, may at any time be used on a much larger plate, the only objection to always choosing a lens of this class for landscape work being that the lens which will fulfil these requirements the best is the Orthostigmat (anastigmat), and may be too expensive. If this lens is precluded on account of its price, it is better to use a medium-angle lens for medium-angle work and an ordinary wide-angle lens for wide-angle work.

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*This lens, the No. 5A.B.S.C.O., has single combinations of 12½ and 14¼ focus respectively.

Distortion in landscape work.

In those cases where it is desirable to make a greater use of the rising front than the lens will permit in the ordinary way, the camera may be tilted and the distortion, if sufficiently marked to be unpleasant, may be corrected by the use of the swing back. In obtaining pictures of landscapes with no architecture included in the subject near the edge of the field, distortion is scarcely noticeable, a little additional inclination given to a "weeping willow" being hardly likely to attract attention.

SECONDARY CONSIDERATIONS.

Secondary considerations.

(1) Brilliancy.
(2) Curvature of field.
(3) Distortion.

Brilliancy.

(1) Brilliancy is of interest in landscape work in so far as it effects the possible range of tones employed in the monochrome transcript of nature. Good lenses vary little in this respect if they have not more than four air surfaces. Some of the very best work that has been done at any time has been with the single landscape lens with its two reflecting surfaces only. Fast plates and fast lenses, carelessly used, tend to over-exposure, and a flat result follows as a matter of course. Many defects put down to a lack of brilliancy in the lens may be more correctly ascribed to incorrect timing of the exposure.

Curvature.

(2) Curvature of field:—This is a defect that should not exist in a lens if it is to be used for landscape work only, though here it does not cause such unpleasant results as in more diagrammatic work; nevertheless, if an important element of the picture lies near the edge of the field, it may be necessary to stop down the lens to get sharpness when, for other reasons, it would have been advantageous to use the largest aperture the lens possessed. Long focus lenses are recommended for landscapes, and they give a sufficiently flat field when used on a small plate.

Distortion.

(3) Distortion:—This is not a serious drawback in landscape photography, but cannot be allowed to pass, for street scenes or buildings. It is also a defect that is only apparent in short focus lenses and need not here claim too much attention, as there is nothing in a landscape that is so rigid as to show distortion; it hardly matters if the old oak appears twisted a little more than is actually the case.

Choice of a lens for landscape work.

There is no other branch of work where so much latitude can be allowed in the choice of a lens, but the advice may be given to "buy the best." A lens of a cheaper type may do all that is required in nearly every case, but there will occasionally be some scene that calls for special qualities—it may be great rapidity or flatness of field, and if the lens be not capable of responding to the demand, an opportunity will be lost.

Convertible Orthostigmat.

The "Convertible Orthostigmat" seems to have special qualifications for landscape and general work—as a whole it is rapid, combining the necessary qualities for street scenes, pictorial and telephoto work with or without figures, and in its two combinations it provides at the same time excellent long focus landscape lenses, suitable for any effort on the part of the most careful and artistic worker.

Diagram of most suitable lens.

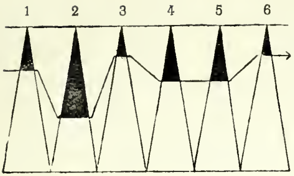

Figure 118.*

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required; the less "black" that appears, the less of that particular quality is essential.

Figure 118 expresses the properties required in a lens for landscape and general photography, showing that no property is of overwhelming importance. A comparison between this figure and those in the previous section will show that a useful landscape lens can be selected from any one of the types.

ARCHITECTURAL PHOTOGRAPHY.

Architecture

This subject recalls memories of the days when one was a beginner in the art, and how, after making libellous representations of one's good-natured friends, it became clear that the post of court photographer could be no sinecure. After having chased the family dog and the family cat over the flower beds in the vain hope of obtaining a picture like one of Landseer's, one turned in despair for advice to a friend of mature experience, who recommended one to photograph the house. It has no sensitive feelings, neither will it run away, what is more, it will remain still during any length of exposure. The advice was good, a picture was obtained—it was hard to recognise as the house, for the lines were falling in. The camera being near the ground, too much foreground and too little house had appeared on the focussing screen, and so the camera had been tilted, and the photograph showed the house apparently falling backwards; the use of the swing back and rising front were at that time unknown. Such experiments give the beginner an insight into the use of his apparatus, and are the most certain methods of teaching manipulation.

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* This diagram indicates the degree to which the various qualities indicated are required for a good landscape lens, in each case the more important a property is to the successful working of the lens the nearer does the line approach the apex of the cones and the less black appears. Any lens having a line that runs higher than the one drawn will also be suitable, if lower it will not. If the line is lower at only one point, that quality alone is deficient.

Possibilities of architectural work.

Much that has already been said will apply to the subject of architectural photography, it can be treated diagrammatically or pictorially, it may be used as a series of plates illustrative of various kinds of carvings and designs, or as a medium for the artistic expression to be found in all stone memorials.

The story of architecture.

The grim determination of the Norman Overlord, exemplified in the strength and massiveness of outwork and keep, followed by the high ideals of growing national feeling in the graceful Early English style, culminating in the somewhat over elaboration of the Decorated period a century later is followed by the period of decline in ideals, typified in the shallower, yet still beautiful, work of the Perpendicular artificers. The stately mansions of the later Tudors clearly tell the story of the consolidation of the country, its freedom from internal and external wars; they are no longer fortified, but show a desire on the part of the architect to design the building for the comfort of the inhabitants rather than for their protection; while in our own times a mixed architecture, some good, most bad, none as permanent as what has gone before, denotes a superficiality, a hurry, a curious admixture of wealth and commercialism, occasionally illuminated by a genuine inspiration.

Although the foregoing remarks suggest to the earnest worker scope for individual expression, many people will be content to produce photographs which are records rather than pictures, and the discussion of the lens will be confined to its power of producing a correct copy.

PRIMARY CONSIDERATIONS.

Primary considerations.

(1) Focus.
(2) Distortion.
(3) Complete angle of view.

Focus.

(1) Focus:—In no other subject does the question of the focus that is most suitable, present so many difficulties. No one length of focus can be recommended. In the interior of a cathedral it is difficult to select an ideal position for the camera—one cannot get further away from, say, an organ screen than is permitted by the wall at the west end, and the view may have to be taken at close quarters; and similarly, it is often impossible to get close to some piece of detail or carving without the use of scaffolding. Therefore, to be ready for any emergency the architectural photographer must have lenses of different foci—one should be of short focus, say 5 or 6 inches for a half-plate, not longer than the longest dimension of his plate, and with this lens views can be taken at close quarters that would otherwise be impossible. Another lens should have a focus about half as long again, say 9 inches for the half-plate; this will be the lens, used for most exteriors and interiors. It should be used in preference to the shorter focus one wherever possible, as it will not give unduly exaggerated perspective. A third lens should be added to complete the photographer's outfit, and that should be about 12 inches or 15 inches focus, or, better still, be a telephoto attachment to fit the short focus lens giving a long range of foci, from 15 inches to 50 inches; with this lens inaccessible details can be photographed on a large scale. The peculiar properties of this useful adjunct are fully discussed under Section VII.

Lenses for architectural work.

The telephoto lens.

Distortion.

(2) Distortion :—A lens which possesses distortion to any appreciable degree should not be employed. A single lens which would give distortion at the edge of the field when used on a large plate can be used on a small one over the area that is free from this error. As contrasted with those of nature, the works of man abound in straight lines. No landscape is ever composed of straight lines, no hill or river ever crosses the view from point to point as does a Roman road. It is difficult to recall any natural objects which possess clear cut edges, but wherever man appears he creates them. The telegraph poles on the Cape to Cairo railway supply more straight lines than the heart of Africa itself could have produced.

Straight lines.

Architecture, depending as it does for its beauty upon the arrangement of its lines as much as upon its light and shade, requires that the lens chosen for its portrayal shall copy accurately and give no distortion.

Angle of view.

(3) Total angle of view :—The total angle of view of a lens to be used for architectural photography should be considerably greater than that required to cover the plate—to explain the advantage of this let the photographer suppose that he is facing the west front of a cathedral. In order to take in the whole, the eye must look upwards, and the camera must follow suit unless a single doorway and a lot of paving stones alone are to be photographed. But if the camera is pointed up, as suggested, the appearance of the west front will be like a pyramid, the upright lines slanting towards each other as if it were falling over backwards. There are two methods of overcoming this trouble.

Tilting the camera.

(1) By the swing back.
(2) By the rising front.

Swing back and rising front.

(1) The first is the one most commonly used when lenses include small circles of illumination. If the camera back which carries the plate

Swing back.

Untruthfulness of the swing back.

holder be arranged so as to be parallel with the cathedral front (vertical), the lines will no longer slant together, but will be straight and parallel, though only sharply defined in the centre, the top and bottom being fuzzy ; sharpness throughout may be obtained by stopping down sufficiently. This method has the disadvantage, that although the lines may be rendered straight the height of the building will be shortened, and in so far the picture will not be truthful.

Rising and cross front.

(2) By the use of the rising front:—This second method is carried out by placing the camera square on the ground, the lens board and plate back being both parallel to the front of the cathedral. The lens itself is raised so as to include more of the top of the building and exclude foreground. This is a better method of obtaining the required result, not only because the drawing of the building will be correct, but because a good lens* need not be used at such a small aperture, as is necessitated by the use of the swing back. It is obvious that in order to do this a lens must be capable of covering a much larger plate than the one upon which it is used in the ordinary way, in other words, it must have a wide angle of view.

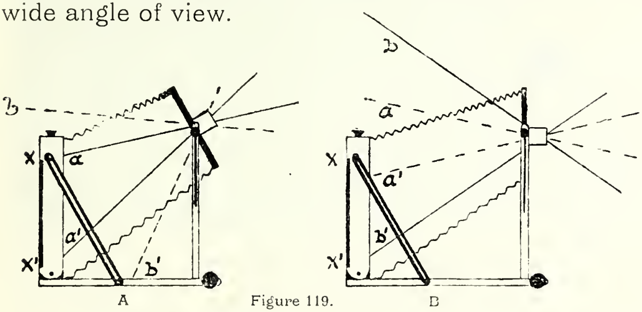

Figure 119.

The foregoing will be illustrated by reference

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*The field of a good lens (orthostigmat) is flat right up to the edge of the circle illuminated.

Explanation of swing back and rising front.

to figure 119. In A (figure 119) the camera is tilted, and the two lines (aa′) represent the limit of the circle of illumination of the lens, which is only just sufficient to cover the plate, (bb′) being the limits of the same circle in a lens which illuminates a larger area. Where method No. 1 is employed either lens fulfils its function, that is, it covers the plate XX′. In B (figure 119), when the method of the rising front is used, the cone (aa′) is insufficient to include all the plate XX′ within its limits—a lens illuminating a cone only that size would leave more than half the plate blank. On the other hand, a lens with an angular width of cone equal to (bb′) will cover the plate XX′, so that no portion would be blank. Figure 120 (A & B) is the appearance of the plate under the conditions indicated. O is the position of the lenses in each case (aa′ and bb′), being the limit of the circle of illumination in each case also.

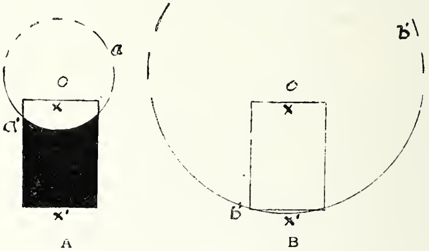


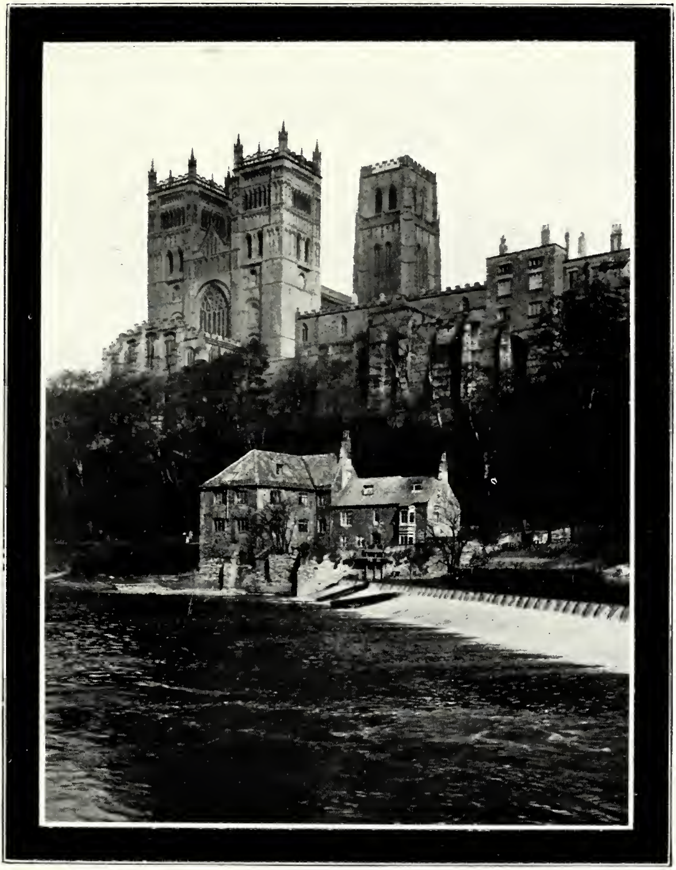
Figure 120

This, then, is a sufficient reason for choosing a lens capable of including a wide angle of view for architectural photography. With scarcely any exceptions, all purely architectural subjects require the rising front to be used to some extent, as it is seldom that the camera itself can be placed on a level with the centre of the required view. In interiors it is often so dark that it is difficult to see if the corners of the plate are illuminated properly, and if the lens covers a large circle no fear need be felt on this account.

See page 239.

PLATE XXXVI.

DURHAM FROM ACROSS THE WEIR.



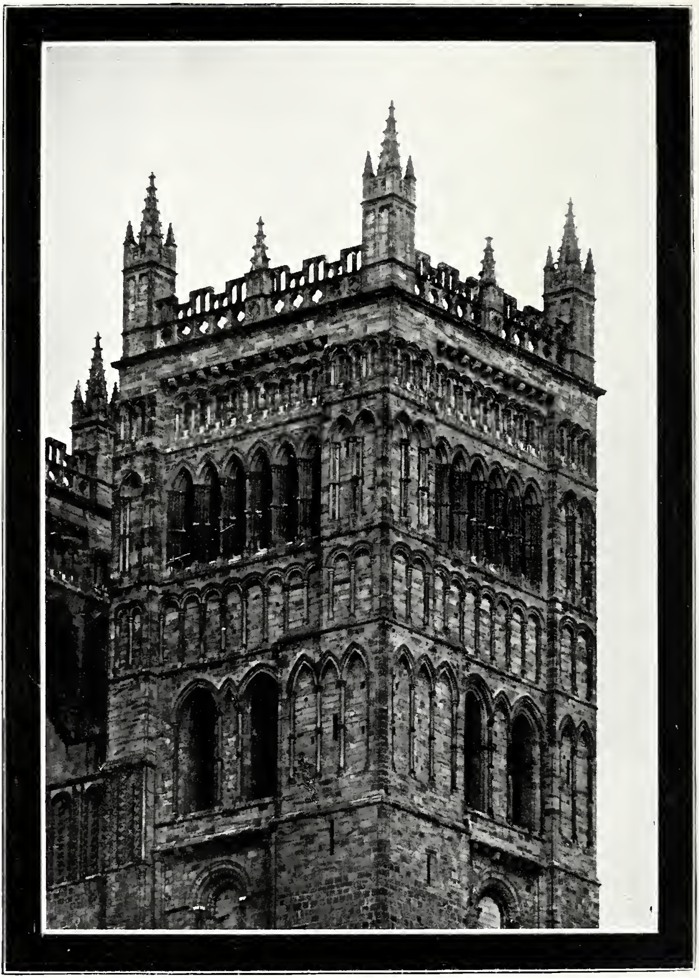
Negative by *H. Andrews.*

From a photograph taken with a No. 5 Beck-Steinheil Orthostigmat, 7⅛-inch focus, f/6·3.

See page 239.

PLATE XXXVII.

ONE OF THE WEST TOWERS OF DURHAM CATHEDRAL.

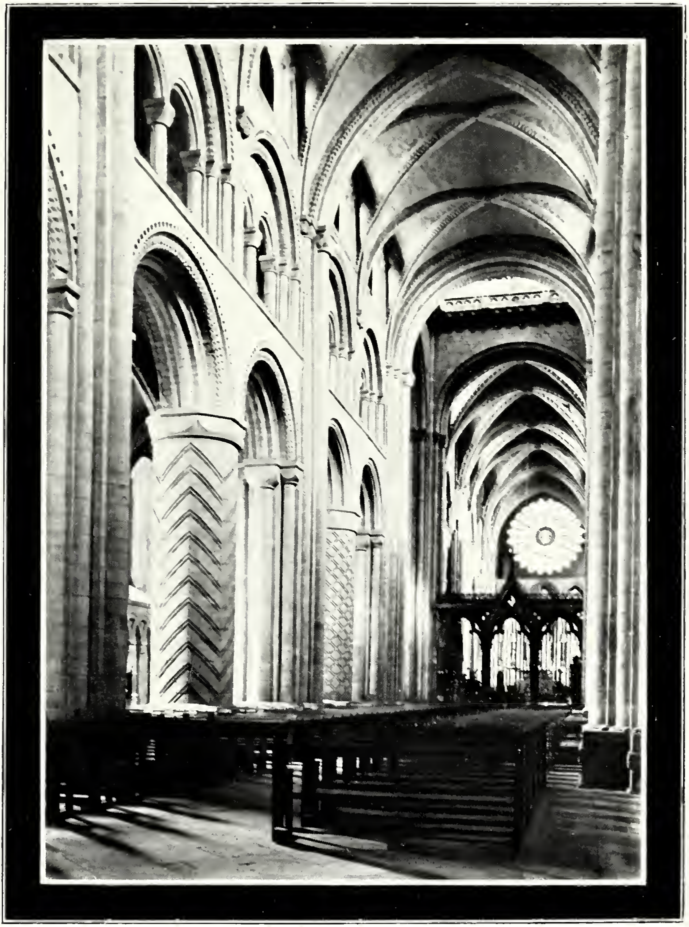


Negative by *H. Andrews.*

From a telephotograph taken with a No. 5 Beck-Steinheil Orthostigmat and a No. 4 Standard Power Attachment, magnification 5 times. It is taken from the same standpoint as plate XXXVI.

See page 239.

PLATE XXXVIII.—DURHAM CATHEDRAL, INTERIOR.

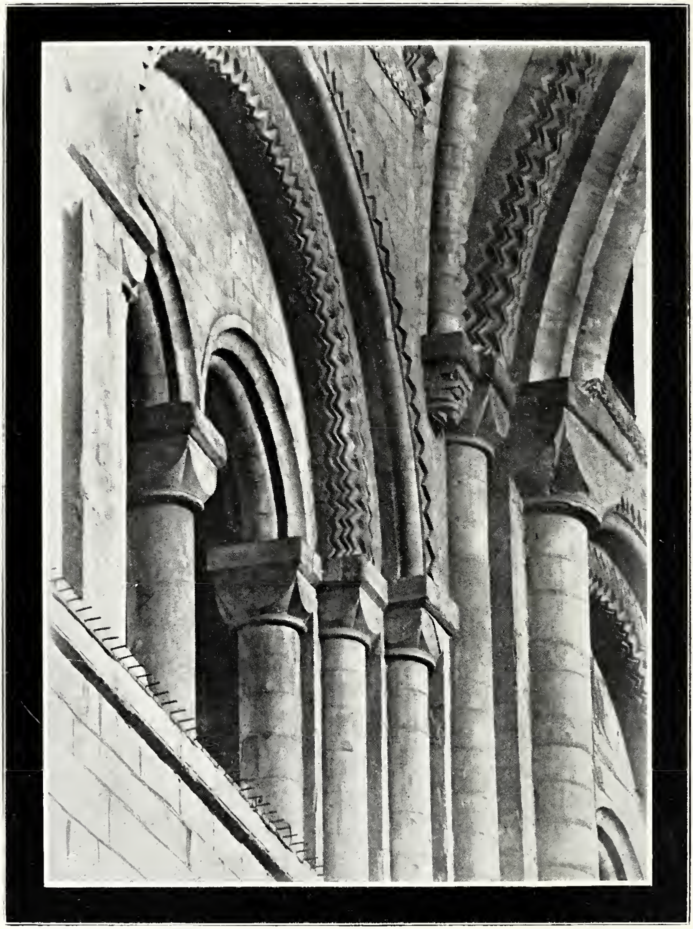


Negative by *H. Andrews.*

From a photograph taken with a No. 5 Beck-Steinheil Orthostigmat, 7⅛-inch focus, f/6·3.

See page 239.

PLATE XXXIX.—INTERIOR OF DURHAM CATHEDRAL.



Negative by *H. Andrews.*

From a telephotograph taken with a Beck-Steinheil low power Telephoto Attachment, magnification 5 times. It is taken from exactly the same position as plate XXXVIII.

PHOTOGRAPHIC LENSES

SECONDARY CONSIDERATIONS.

Secondary considerations.

(1) Rapidity.
(2) Curvature of field.

Rapidity.

(1) Rapidity:—This quality is of some importance in architectural work, for although these subjects remain stationary it is often inconvenient to give the prolonged exposures that badly lighted interiors require with a slow lens. A special service may require the hurried removal of the apparatus before the subtle differences between shadow and deeper shadow have been recorded on the sensitive plate. It is not infrequent that an exposure of half an hour is necessary to do justice to some intricate interior with many dark recesses and unequally lighted masses of stonework, and after all there are only a limited number of half-hours that can be used in a day's photography.

A further advantage of a rapid lens is that it is often difficult to see the picture on the ground glass clearly enough to focus accurately by and a large aperture greatly helps in making this adjustment. Before actually exposing the lens may be stopped down to a smaller aperture to get the required depth, but the larger aperture can be made use of to focus with.

The question of rapidity brings in its train that of depth of definition. This plays an important part in architectural work, as the different portions of the picture lie at different distances from the lens, some almost as close as a full-length figure would be in a studio, while others are at a considerable distance, and they should all be rendered with a fair degree of sharpness. It is not advisable to put some portion out of focus as in landscapes; the effect of distance should be obtained by perspective, and this, too, is the most effective means of giving an appearance of solidity. The eye is so used to examine each object in an interior in turn that it is not safe to leave any portion badly defined.

An example.

Consider, for instance, a dining-hall; there is the oak table, the near edge is only 5 feet from the lens, while the ingle nook may be 30 feet; if the lens be a wide-angle one, say a 4-inch on a half-plate, this will mean a difference between the two focal points of ½-inch. To get both the table and the ingle nook adequately sharp, an aperture not larger than f/32 will have to be used. In a large interior so great a depth will not usually be required, so that f/11 or f/16 is often sufficiently small. Occasionally, though very seldom, the background may be placed slightly out of focus, more especially if it is intended to draw attention to any particular object or portion of the view; this is a matter that each photographer must solve for himself.

When to photograph interiors.

One other point might be touched upon in this connection—it is usually much the wisest plan to photograph interiors when the sun is not shining; a dull, grey day being the best. The shadows are then less intense, the high-lights less brilliant, while the delicate effect of carved capital and clustered columns can be better rendered, the tone and distance are nearer the truth, and the effect of patchiness avoided. No rules can be given, a slanting sunbeam glancing on to a dark oak screen may give life and brightness to a grey old church, though to photograph such violent contrasts the plate must be given ample exposure, or the sunbeam will leave a slash of white without detail or tone which will mar the print. Exposures, even in extreme cases, must be made for the shadows.

Curvature of field.

(2) Curvature of field :—A slight amount of saucer-shaped curvature of field may be no disadvantage in interior or street scene work when the edge of the view is nearer to the camera than the centre, for, as has been

previously mentioned, objects close to the camera come to a focus further from the lens than do distant ones. However, a lens with a flat field is the most suitable, for there are quite sufficient difficulties to distract the attention without adding curvature of field.

Diagram of most suitable lens.

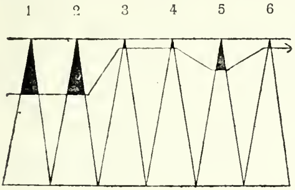


Figure 121.*

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required; the less "black" that appears, the less of that particular quality is essential.

The lens most nearly approximating to figure 121 in its essentials is the one that is most nearly the ideal for architectural work.

LENSES FOR HAND CAMERAS.

Hand-camera lenses.

The vast majority of amateur photographers are hand-camera workers, and the opinion seems to exist that this is the easiest branch of work for the beginner to start upon; in reality it calls for a degree of perfection in the lens, that is not necessary for stand work, it being easier to do good work with a poor lens on a stand camera than on a hand camera.

PRIMARY CONSIDERATIONS.

Primary considerations.

(1) Central definition.

(2) Rapidity.

Central definition.

(1) Central definition:—A hand-camera lens should give perfect definition in the centre of

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[*] The considerations of the most importance are, first Distortion and angle of view, and secondly, Rapidity.

the field, and this should be expected and demanded whatever type of lens is chosen; it should also be free from flare.

Rapidity.

(2) Rapidity:—The fact that instantaneous exposures are required in hand-camera work means that both the lens and the sensitive film must be as rapid as possible. The most rapid exposures, 1-100th to 1-1000th of a second, need a specially brilliant light and a lens with an aperture of about f/6; exposures from 1-10th second to 1-100th do not require more than f/11 or so, if the light is fairly good. A large aperture lens is always an advantage, as the full aperture need only be used in poor light or for exceptionally short exposures, and it is useful to have this to fall back upon under such conditions.

Depth of focus.

(3) Depth of focus:—This is particularly required for snap-shot work, as it is difficult to gauge the distance of an object from the camera, and more than one plane must be sharp at once.*

Covering power.

(4) Covering power:—Great rapidity, together with covering power, can only be combined in the best of lenses—great rapidity and depth of focus can never be obtained in one lens. The small aperture required to obtain depth of focus means loss of rapidity; but it should be remembered that a short focus lens gives more depth than a longer one, therefore, if a lens is sufficiently perfect to cover a large plate with a short focus, it should be chosen in preference to one of a longer focus. For instantaneous work a $4\frac{1}{8}$-inch Orthostigmat will give sharp definition over the whole of a $\frac{1}{4}$-plate or, indeed, of a 5 × 4 plate at full aperture, while to obtain the same result on a $\frac{1}{4}$-plate with a rectilinear lens at f/6·3, a $6\frac{1}{2}$-inch lens would have to be used; the difference of depth of

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*It is of great advantage to know this distance accurately for any given aperture. The cornex index gives this accurately.

focus in these two cases would be so great that the second lens would only give *half* that of the first, and the rectilinear would have to be stopped down to f/14, or to about 1/5 the rapidity of the Orthostigmat to give a like depth of focus. Thus it is that where price can be ignored there is little trouble in selecting the most suitable lens, as the Orthostigmat (anastigmat) possesses all the requisite properties, and it remains only to choose a suitable focus for the size of camera decided upon.

Choice of focus.

This choice must depend upon three considerations.

(1) Depth of focus.
(2) The size of the plate.
(3) The angle of view to be included.

Except under special conditions where there is opportunity to focus exactly and certainly, a lens having a longer focus than 7½ inches should not be employed on account of its lack of depth of definition; irrespective of the camera size. Suppose a picture of an approaching cyclist is the subject in hand; if the lens, when focussed for 20 feet, has only sufficient depth to give a sharp picture of objects between 18 and 22 feet, it is impossible to gauge the distance sufficiently accurately to ensure success. It is for this reason that snap-shot cameras are rarely successful if of a larger size than 5 × 4, or at the utmost ½-plate (6½ × 4¾), a larger camera requiring a longer focus lens to cover the plate. It is for the same reason, that fixed focus cameras are not made larger than this size.

The conclusion arrived at from this is that the best focus to choose is the shortest that will sharply cover the plate, and the following are those that comply with this condition if the lens is to be of the Orthostigmatic (anastigmatic) type.

Focus of orthostigmat for certain plates neglecting perspective.

Plate size.	Focus.
3½ × 2½ inches	3½ inches.
4¼ × 3¼ ,,	4⅛ ,,
5 × 4 ,,	4¾ ,,
6½ × 4¾ ,,	6 ,,

Short focus lenses give too great an angle of view for correct perspective rendering, and this third factor is of so much importance to most photographers, that they prefer lenses of a longer focus than those listed above. The scale on which objects are reproduced is too small, and the camera would have to be too near them to be convenient in practice. For general work, therefore, the following are the foci recommended.

Most suitable focus to choose for the same plates.

Plate size.	Focus.
3½ × 2½ inches	4⅛ inches.
4¼ × 3¼ ,,	4¾ ,,
5 × 4 ,,	6 ,,
6½ × 4¾ ,,	7⅛ ,,

If the camera is to be used for figure or animal studies it is preferable to use a still longer focus, and to rely more upon the focussing scale than upon the depth for the requisite sharpness. To produce pictorial work a longer focus is preferred by some, for it must not be supposed that a hand camera is unsuitable for artistic work—it is the only means of obtaining natural groups, and even for landscapes, it can be used so rapidly that the glories of many a gleam of sunlit country can be caught, that would have passed before a stand camera could have been erected. The modern hand camera, with its perfect lens, shutter and plate, is as good as its more complicated rival, the stand camera, but, it is its ease of use, that tends to beget carelessness. If a thing can be done easily it will often not be done well.

Aperture for rapid work.

There is, therefore, little difficulty in choosing a suitable lens if price is not of first importance. A rapidity of not less than f/6·3 is all that is required; indeed, a more rapid lens than one working at about f/6 should not be chosen for hand-camera work, for optical as well as other reasons. The above remarks indicate the best focus.

If price is of importance the choice requires further consideration, because some of the properties of the better lens must be sacrificed. In order to render the problem more simple, it is useful to divide hand cameras into two classes.

Classification of hand-camera work.

(1) Those in which unusually quick exposures are to be made, such as the focal plane cameras giving exposures from 1-100th to 1-1000th of a second.

(2) Those in which exposures quicker than 1-100th of a second cannot be given.

High-speed work.

The first class of hand cameras is intended primarily for photographing objects in very rapid motion, such as galloping horses, athletes, trains, sea gulls, etc., and for these cameras a rapid lens is of the utmost importance. If an Orthostigmat (anastigmat) is too expensive the choice should fall on a Biplanat, with its aperture of f/5·8; this lens will give as sharp definition near the centre of the field as could be desired, but towards the corners will show a slight falling off unless a somewhat smaller aperture be employed. This is not as serious a fault as at first sight might appear, because in this class of work the object of interest being photographed is usually situated near the centre of the plate and the quality of the definition in the corners is of little importance, less so than would be the case in a landscape or street scene. When the camera is to be used with moderate exposures, the Biplanat can be stopped down to such a point that full use can be made of its covering power; it therefore makes a good substitute for the Orthostigmat (anastigmat) at a much lower price. For this first type of camera a slower lens cannot be recommended, and the greatest care is necessary in choosing it to see that the central definition is beyond reproach; the focus chosen, if it be a lens other than the Orthostigmat, should preferably be a little longer, say 5½ inches, for a quarter-plate, as this will aid the covering power to a considerable degree.

Moderate speed work.

The second type of hand camera is by far the commonest, it gives exposures from 1-10th to 1-100th of a second. For ordinary snapshots of street scenes, landscapes or figure subjects, 1-20th second or thereabouts is by far the most useful all-round exposure, and it is sufficiently quick for moving objects if they are not near to the camera. A 1-40th or 1-80th second may be required if they are moving at right angles across the field, and not towards or away from the operator. When in doubt give 1-20th second; if this speed is adhered to and the light is good, it will allow of the lens being stopped down to f/11 or f/22; and with large apertures, enables a printable negative to be obtained on the dullest days.

Types of lenses suitable.

The most rapid lens is also desirable for this class of camera, and the Orthostigmat or Biplanat are for this reason better than the less rapid types. The rapid rectilinear type (double aplanat, symmetrical, etc.) is very good, as it is sufficiently rapid for most subjects, and is moderate in price. Care should be taken, however, before procuring one, or a camera fitted with one, to see that it is by a good maker. This type of lens is best used with an aperture of f/11, only opened up to its usual full aperture f/8 for portraits and figure studies. It is rarely necessary to have recourse to this aperture, and when the light is sufficient for an exposure of 1-40th of a second it is better to stop down to f/16 and give 1-20th, unless the objects being photographed are in very rapid motion.

Focus of R.R. Lens to choose.

The best focus to choose, if a rectilinear type of lens is to be employed, is open to a difference of opinion—if it is to be used frequently at f/8 the very best lens of the type should be unhesitatingly purchased, and the focus should not be less than 6 inches for a ¼-plate in order that the picture may be sharply defined up to the corners of the plate. If the worker is content with f/11 as his general full aperture, a 5½-inch lens will do all that he requires, and has considerably more depth of focus, while so much care need not be taken in judging distances. Some even prefer a 5-inch, but if it be of a cheap make, the focus should not be less than 6 inches.

The single achromatic view lens is cheap, and may form an excellent hand-camera lens of small aperture, either f/11 or f/16. It should be carefully chosen for the camera with which it is to be used, and which should be of the box model type without rising front. This type of lens gives distortion, the degree depending largely on the care with which it is designed for the particular camera to which it is fitted.

The double meniscus for hand cameras.

The double meniscus is a lens that is in some respects superior to the single lens for hand-camera work, as it has no distortion and a very flat field; but it is slow, its full aperture being between f/11 and f/16. Its chief drawback is that it possesses a chemical focus, so that its use is restricted to box cameras or focussing cameras without ground glass.

From the above the following conclusions are arrived at, viz., that the best lens for the first class of hand cameras—that giving extra rapid exposures, is

Lenses for high-speed work.

(1) The Orthostigmat, 4¾-inch focus, f/6·3.*
(2) The Biplanat, 5½-inch focus, f/5·8.*
(3) The Double Aplanat, 5½-inch focus, f/7·7.*

For the second class of hand cameras there is a larger selection of suitable lenses.

Lenses for moderate speed work.

(1) The Orthostigmat, 4¾-inch focus, f/6·3.*
(2) The Biplanat, 5½-inch focus, f/5·8.*
(3) The Double Aplanat, 5½-inch or 6-inch focus, f/7·7 or f/8.*
(4) The Double Meniscus, 5½-inch or 6-inch focus, f/11 or f/16.*
(5) The Single View Lens, 5½-inch or 6-inch focus, f/11.*

The hand camera.

There are some questions connected with the use and construction of hand cameras which, although not belonging strictly to the domain of lenses, so largely influences their proper use that it will not be out of place to briefly refer to them.

Holding the camera.

The length of exposure which it is desirable to give under a certain set of conditions has to be modified according to the nature of the lens. If a camera is held in the hand during exposure it will not be perfectly stationary, the breathing, the beating of the heart and the constant balancing of the muscles which control the movements of the body preclude absolute rigidity, and consequently the exposure must be short enough to ensure that the camera has not perceptibly moved during that time. A box form camera, steadied on one hip, can be held with less movement than a folding one held in the hands, and experience has shown that many can hold a camera of the former type steady for a quarter of a second or even longer; but unless special care is taken an exposure longer than 1-15th or 1-20th of a second will not be safe.

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* These figures are for the standard English quarter-plate size; they can in both tables be slightly lengthened for pictorial or portrait work.

A heavy set off requiring great pressure to use is a serious drawback, as the effort of making the exposure is liable to shake the camera at the moment of release. If the camera be used over the running engines of a steamer, or on a small sailing vessel where there is sure to be considerable movement, 1-40th second is the longest exposure that can be safely given.

Duration of exposure.

The knowledge of what exposures are necessary to obtain sharp pictures of rapidly moving objects is one acquired by practice. Theoretically speaking, it is a matter of impossibility to obtain an absolutely sharp image of any object in motion, inasmuch as the duration of the exposure would require to be infinitely small. In practice, however, it will be found that the image of any point upon the negative will appear sharp, provided it be not displaced during the act of exposure to a greater distance than 1-100th of an inch; even 1-50th of an inch displacement will give a fairly good picture. To guide the reader in this respect the following rough table has been prepared of the exposures required to take objects moving at right angles to the camera. When the object is not moving at right angles to the camera, but towards it or away from it, the exposures may be increased. If the objects are moving across the line of sight at 45 feet they may be doubled, if at 30 feet they may be quadrupled, and if coming straight towards or away from the camera, the exposures given above may be multiplied by 8.

TABLE OF SPEEDS REQUIRED FOR VARIOUS SUBJECTS AT VARIOUS DISTANCES.

Table of speeds required for moving objects.

	At 12 yards.	At 30 yards.	At 60 yards.	At 100 yards.
Express trains at 60 miles per hour	1-1000	1-400	1-200	1-100
Express trains at 40 do.	1-600	1-300	1-150	1-75
Freight trains at 20 do.	1-300	1-120	1-60	1-30
Horse galloping	1-400	1-160	1-80	1-40
,, ,, (fetlocks blurred)	1-200	1-80	1-40	1-20
,, trotting	1-300	1-100	1-40	1-20
,, and carriage at ordi- speed	1-80	1-40	1-20	1-10
,, walking	1-40	1-20	1-10	1-5
Man jumping hurdles, etc.	1-200	1-80	1-40	1-20
,, running races, etc.	1-150	1-80	1-40	1-20
,, ,, slowly	1-80	1-40	1-20	1-20
,, walking	1-40	1-20	1-10	1-5
Grazing cattle	—	1-10	1-5	—
Sailing vessels	—	—	1-40	1-20
Steamers	—	—	6	1-40

The motions of the human face are seldom so rapid, but when the head itself is steady a sharp picture will be obtained with 1-5th or 1-10th of a second.

Depth of focus.

If the table given is used in conjunction with an actinometer or with a correct knowledge of the value of light, it is an easy matter to decide which is the smallest stop that can be used to give a fully exposed negative. In fixed focus hand cameras the range of objects which will be sharp at one time, is dependent solely on the focus of the lens and the aperture at which it is to be used; the smaller the aperture the greater being the depth of focus. In small cameras with a lens of say 4-inch focus and an aperture of f/11, the range will be from 12 feet to the horizon, but with lenses of 5 to 6-inch focus the range will be from 25 feet to the horizon, so that for photographing anything nearer than these distances some method of focussing is necessary. The Frena magnifier system is the only one applicable to fixed focus box-form cameras; it consists of placing supplementary lenses in front of the photographic lens, and is fully described in the next section (VII.). The method used with focussing cameras is by the addition of a scale of distances. A pointer on the lens is set to a figure representing the plane of best definition, and a certain distance on each side of this plane will be sharp, how much this will be is left to the photographer to guess. This has been recently improved upon by a method patented by Messrs. R. & J. Beck, Limited, and called the "Cornex Index." The amount of depth on each side of the sharpest focus is shown for each aperture on the Index, so that this system is as convenient as the Frena magnifiers (also plate XLIII.).

Cornex index.

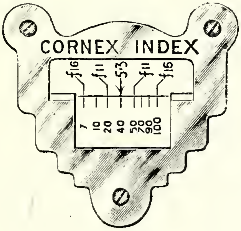

Figure 122.

Focussing scales necessitate the accurate judging of distances in order that the results may be sharp, and practice is required to render the photographer expert. They must be adjusted to each individual camera with accuracy, and the careful photographer will leave nothing to chance but will test his scale on the purchase of a focussing camera. If the scale is accurate it is a more reliable method of focussing, provided the distance of the object being photographed is known, than by the use of the ground glass. Mistakes in focussing on the ground glass are easily made, unless the operator has plenty of time in which to carry out this process.

Focussing scales.

It is useful for the snap-shotter to have a well-defined idea of the distance that a camera should be away from a figure in order to produce a picture of a given size. At what distance away, for instance, should a man be in order to obtain a picture 1 inch, 2 inches or 3 inches high? A simple rule will give the distance. Multiply the height of the man in inches by the focus of the lens, this will give in inches the distance away that the figure must be placed to render the picture an inch high in the photograph. For example, suppose a man is 70 inches high and he is being photographed with a lens of 6 inches focus, 6 × 70 = 420 = 35 feet, this is the distance from the camera at which he must be in order to appear 1 inch high in the photograph. At half this distance ($17\frac{1}{2}$ feet) his picture will be 2 inches, at one-third (11 feet 8 inches) it will be 3 inches.

Rule to find size of a figure on the plate.

INSTANTANEOUS PHOTOGRAPHY.

Instantaneous photography.

Much that has already been said of hand-camera work applies with equal weight to instantaneous photography as such; the question as to whether a stand is used with small hand cameras is chiefly a matter of convenience, but instantaneous work is not limited to small cameras, and in the latter case a stand should always be used. The picture may be focussed on the ground glass, where a stand is in use, and the choice of the lens need not, therefore, be confined to such close limits, because depth of focus is not of so much importance when this is the case; indeed, almost any length of focus can be employed, as the plane of the principal object can be selected. Instantaneous pictures can be taken with even a low-power telephoto attachment in favourable weather. The focus may, therefore, be chosen with a view to the pictorial result or the most suitable angle of view.

Beyond the size of the standard half-plate, instantaneous work becomes more and more difficult, partly because the larger lenses in use require larger shutters, which are difficult to make to move rapidly without introducing vibration ; and partly because long focus lenses of any type, with the exception, possibly, of the Orthostigmats (anastigmats), have to be stopped down to give as sharp results. It is a question whether it is not better to rely on enlargements for instantaneous pictures larger than whole-plate size.

Diagram of most suitable lens.

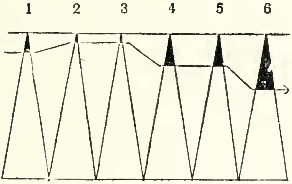

Figure 123.*

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required ; the less "black" that appears, the less of that particular quality is essential.

ENLARGING AND COPYING.

Enlarging and copying

Having reached this heading, photography proper is left behind ; the negative is finished for better or for worse, and a copy or enlargement is the subject with which this chapter is concerned. It is now purely a question of technical knowledge and mechanical skill, not of artistic perception. The same applies to copying works of art or curios, and it is technical considerations that will govern the choice of the lens.

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* Figure 123 is a diagram to show the various properties and their relative importance for hand-camera and instantaneous work, the nearer the line approaches the apex of the cone the greater the extent to which that particular property should be present in the lens.

Explanation of enlarging.

In enlarging—the reverse of the process employed in producing the original photograph takes place. The picture of the landscape in the shape of the negative is projected back through the lens, as it were, on to the landscape. If a negative be placed in the position in which it was taken in the camera, and a sufficiently powerful illuminant be placed behind it, it would be possible, on a dark night, to project the picture back on to the landscape point for point, twig for twig. Of course a full-sized picture is not required, for who has a room sufficiently large to hold a full-sized picture of St. Paul's ?

A picture of any size may be obtained according to the distance away that the screen upon which it is thrown is placed. An enlarging camera is a form of lantern, and is often used in a darkened room in a similar manner to a magic lantern, a piece of sensitized paper taking the place of the ordinary sheet.

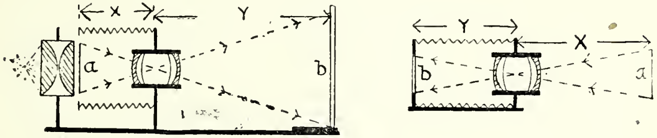
It has already been explained in an earlier section of this book that the nearer an object is to the lens, the longer the distance of the lens from the ground glass. If the sensitive surface be considered as the object, it will be evident that the negative to be enlarged will be further from the lens as the paper is brought nearer to it. Therefore, to obtain enlargements of given sizes there will be certain definite positions with a given lens, both for paper and negative. The distances of the positions of these points are the conjugate foci of the lens. The relation between the conjugate foci governs the size of the image.

If the conjugate foci are the same, then the original and secondary images are the same size; if the primary focus be a quarter that of the secondary the final image is four times the original size of the negative, if the relation is 1 to 6, then it is six times and so on. The reverse is the case in reducing.

Explanation of copying.

Primary and secondary focus.

In enlarging, the primary focus is considered as the distance from the negative to the lens (the shorter distance), while in copying it is the distance from the sensitive surface to the lens. In figure 124 A is the arrangement for enlarging, while B is that for copying; the direction of the light is indicated in both cases by the arrow heads on the lines. X is the primary conjugate focus and Y is the secondary; it is the relation between X and Y that gives the degree of magnification or reduction. (a) is the negative or object and (b) the sensitive surface that is to receive the final image.



A. B.

Figure 124.

To find the distances X and Y for lenses of varying focus, the following table has been prepared, which will give (1) the distance of the lens from the negative or object, and (2) the distance of the lens from the sensitive surface. The sum of the two will give the total distance over all, and will help the photographer to ascertain whether his enlarging bench is capable of producing a given size of picture.

TABLE OF CONJUGATE FOCI FOR ENLARGING AND REDUCING.

Table of conjugate foci.

Focus of Lens.	Number of times of Enlargement or Reduction.								Enlarging.*	Reducing.*
	1	2	3	4	5	6	7	8		
3	6	$4\frac{1}{2}$	4	$3\frac{3}{4}$	$3\frac{3}{5}$	$3\frac{1}{2}$	$3\frac{3}{7}$	$3\frac{3}{8}$	*x*	*y*
	6	9	12	15	18	21	24	27	*y*	*x*
$3\frac{1}{2}$	7	$5\frac{1}{4}$	$4\frac{2}{3}$	$4\frac{3}{8}$	$4\frac{1}{5}$	$4\frac{1}{12}$	4	$3\frac{15}{16}$	*x*	*y*
	7	$10\frac{1}{2}$	14	$17\frac{1}{2}$	21	$24\frac{1}{2}$	28	$31\frac{1}{2}$	*y*	*x*
4	8	6	$5\frac{1}{3}$	5	$4\frac{4}{5}$	$4\frac{2}{3}$	$4\frac{4}{7}$	$4\frac{1}{2}$	*x*	*y*
	8	12	16	20	24	28	32	36	*y*	*x*
$4\frac{1}{2}$	9	$6\frac{3}{4}$	6	$5\frac{5}{8}$	$5\frac{2}{5}$	$5\frac{1}{4}$	$5\frac{1}{7}$	$5\frac{1}{16}$	*x*	*y*
	9	$13\frac{1}{2}$	18	$22\frac{1}{2}$	27	$31\frac{1}{2}$	36	$40\frac{1}{2}$	*y*	*x*
5	10	$7\frac{1}{2}$	$6\frac{2}{3}$	$6\frac{1}{4}$	6	$5\frac{5}{6}$	$5\frac{5}{7}$	$5\frac{5}{8}$	*x*	*y*
	10	15	20	25	30	35	40	45	*y*	*x*
$5\frac{1}{2}$	11	$8\frac{1}{4}$	$7\frac{1}{3}$	$6\frac{7}{8}$	$6\frac{3}{5}$	$6\frac{5}{12}$	$6\frac{2}{7}$	$6\frac{3}{16}$	*x*	[illegible]
	11	$16\frac{1}{2}$	22	$27\frac{1}{2}$	33	$38\frac{1}{2}$	44	$49\frac{1}{2}$	*y*	*x*
6	12	9	8	$7\frac{1}{2}$	$7\frac{1}{5}$	7	$6\frac{6}{7}$	$6\frac{3}{4}$	*x*	[illegible]
	12	18	24	30	36	42	48	54	*y*	*x*
$6\frac{1}{2}$	13	$9\frac{3}{4}$	$8\frac{2}{3}$	$8\frac{1}{4}$	$7\frac{4}{5}$	$7\frac{7}{12}$	$7\frac{3}{7}$	$7\frac{5}{16}$	*x*	*y*
	13	$19\frac{1}{2}$	26	$32\frac{1}{2}$	39	$45\frac{1}{2}$	52	$58\frac{1}{2}$	*y*	*x*
7	14	$10\frac{1}{2}$	$9\frac{1}{3}$	$8\frac{3}{4}$	$8\frac{2}{5}$	$8\frac{1}{6}$	8	$7\frac{7}{8}$	*x*	*y*
	14	21	28	35	42	49	56	63	*y*	*x*
8	16	12	$10\frac{2}{3}$	10	$9\frac{3}{5}$	$9\frac{1}{3}$	$9\frac{1}{7}$	9	*x*	*y*
	16	24	32	40	48	56	64	72	*y*	*x*
9	18	$13\frac{1}{2}$	12	$11\frac{1}{4}$	$10\frac{4}{5}$	$10\frac{1}{2}$	$10\frac{2}{7}$	$10\frac{1}{8}$	*x*	*y*
	18	27	36	45	54	63	72	81	*y*	*x*
10	20	15	$13\frac{1}{3}$	$12\frac{1}{2}$	12	$11\frac{2}{3}$	$11\frac{3}{7}$	$11\frac{1}{4}$	*x*	*y*
	20	30	40	50	60	70	80	90	*y*	*x*
11	22	$16\frac{1}{2}$	$14\frac{2}{3}$	$13\frac{3}{4}$	$10\frac{1}{5}$	$12\frac{5}{6}$	$12\frac{4}{7}$	$12\frac{3}{8}$	*x*	*y*
	22	33	44	55	66	77	88	99	*y*	*x*
12	24	18	16	15	$14\frac{2}{5}$	14	$13\frac{5}{7}$	$13\frac{1}{2}$	*x*	*y*
	24	36	48	60	72	84	96	108	*y*	*x*

The method of finding the equivalent planes is given in Appendix II. (page 273), and the measurements above are from the front and back planes respectively. In most cases where a doublet is used these measurements can be made from the diaphragm without a serious error being introduced, in the case of a single lens from the back surface. In any non-symmetrical form it should be from the equivalent planes, which must be first found.

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* *x* and *y* are the 2 conjugate foci as explained in (figure 124).

PRIMARY CONSIDERATIONS.

Primary considerations.

(1) Flatness of field.

(2) Distortion.

Flatness of field.

(1) Flatness of field :—In enlarging or copying, one flat picture has to be reproduced on another flat plane—a lens with a flat field is therefore required. Most lenses can be improved, if they have not a flat field, by stopping down, but there are disadvantages in a long exposure besides the waste of time entailed ; and there is always a tendency to a certain chemical spreading of the image and consequent loss of vigour in the result. There is also a risk of something moving during the exposure and, therefore, a lens with a flat field that can be used at a large aperture is an advantage. The Orthostigmat (anastigmat) heads the list in respect of this quality, and is to be chosen by preference for the work. A good rectilinear, if not too short in focus, will do excellent work. The focus best suited for enlarging a given sized negative is of minor importance, provided the lens will give perfect definition over the whole field. A short focus lens is not advisable, because whatever the construction it will not pass as much light to the edges of the field as to the centre. A long focus can only be inconvenient on the score of the length of apparatus that will be necessary.

Distortion.

(2) Distortion : — This is a defect that should not be present in a lens used for enlarging or for copying. A distorted picture may be enlarged with a distorting lens, preferably with the one with which it was taken, and a corrected copy of the view can be procured ; but this is an unusual case, and does not affect the question. If a picture is distorted because it was taken with the camera tilted, and the swing back was not employed to correct

the inclination of the vertical lines, a corrected copy or enlargement can be made by placing the sensitized enlarging paper out of the perpendicular to the required extent, to render the vertical lines parallel.

Secondary considerations.

SECONDARY CONSIDERATIONS.

(1) Rapidity.

(2) Equality of illumination.

Rapidity.

(1) Rapidity has been sufficiently referred to; suffice it to say that rapidity is an advantage, but not an essential.

Equality of illumination.

(2) Equality of illumination :—It is evident that to produce a good enlargement the exposure must be equal over the whole of the sensitive surface, as it would not do to allow more light to pass to the centre of the paper than to the corners, or they would appear lighter than the rest of the picture. It will occasionally happen when a photograph has been taken with a lens working at a very large aperture and a very short exposure, that, although detail appears all over the plate, the centre will print lighter than the edges owing to a slight inequality of illumination. Use can then be made of a lens giving somewhat unequal illumination, but it is only in the hands of a skilled operator that it is safe to employ such a device. It is probably simpler to place a screen between the lens and the enlargement during a portion of the exposure; this screen should be in the form of a circular aperture, and care should be taken that it acts like a vignette and throws no definite shadows.

Inequality of illumination.

It should always be remembered when considering whether a lens be suitable for enlarging or copying, that it will certainly be used at a longer focus than for ordinary field work. A glance at the table on page 210 will show that a $\frac{1}{4}$-plate lens of say $5\frac{1}{2}$ inch focus, if used to enlarge to 12 × 10, will be used 7 inches away from the negative. This means that it will cover better and give more even illumination over the range of the $\frac{1}{4}$-plate than when it was used in the field. A lack of covering power noticeable in the latter case would not be apparent when the same lens is used on the enlarging camera.

To indicate what properties are of importance for this work, figure 125 has been prepared, and a comparison with those diagrams appearing in Section IV. will show that the Universal Orthostigmat (anastigmat) is the best for this work.

Diagram of most suitable lens.

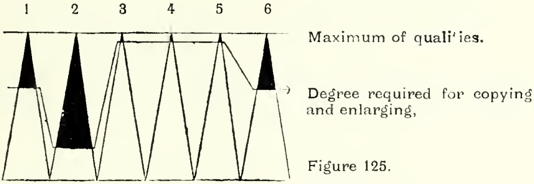

Figure 125.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required; the less "black" that appears, the less of that particular quality is essential.

After the Orthostigmat the choice should fall on the Biplanat, or on a lens of the rectilinear type. There is one point that should be borne in mind in choosing a lens, on no account employ one whose focus is altered by the introduction of a small stop. Focussing will always be carried out at an open aperture, and this must not be altered by the process of stopping down, as any change in the focus from this cause would spoil the definition of the result.

MICRO-PHOTOGRAPHY.

Micro-photography.

It seems hardly possible to leave the subject of enlarging without a reference to micro-photography, though the subject in its complete aspect is beyond the scope of this work. Enlarging itself is a form of low-power micro-photography where a small magnification only is required, and where the photographic lens takes the place of the microscope objective. In rather higher power work the Orthostigmat or a similar lens of a focus of from 1 inch to 3 inches is used; this is found to be the more suitable for powers from 20 to 40 diameters than a microscope objective. Much of the best micro-photographic low-power work is done in an ordinary camera with these lenses. They have, over a large angle, a flatter field than the microscope object glass and quite as perfect correction, their only disadvantage being their comparatively small numerical aperture. Many large microscopes are now made to carry these lenses, and are provided with unusually large bodies, to allow of their full angle of view being used.

Plate XXXI.* represents a photograph taken with a 1-inch Orthostigmat of the stem of a plant, "Juncus lamprocarpus," the magnification being 20 diameters, and all the cell walls are sharply defined.

PHOTO-MECHANICAL WORK.

Photo-mechanical work.

A foreigner is said to have remarked, "Oh, the English are a great nation, they have accomplished so much with the flint instruments of their forefathers."

It is to be feared that the conservative tendencies of which English commerce stands accused have some basis in actual fact, and that in the photo-mechanical trades, for the sake of saving a few pounds, old model or inferior lenses are often employed. The cost of a perfect lens is of no moment if it will save time or electric current, or if it will produce even a slight increase in the quality of the work. A lens will last a lifetime, and if by the expenditure of £30 an advantage is gained, the money should no more be grudged than in the case of an expensive surgical operation. All lenses used for process work are large, and the imperfections which may pass unnoticed in a short focus lens will ruin the work turned out by a larger one.

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* The half-tone process of necessity destroys the quality of definition, so obvious in the original.

Severity of the tests to which process lenses are put.

The essentials are perfect freedom from central and oblique aberrations, and the only type which is thoroughly satisfactory is the Orthostigmat or the Anastigmat; lenses of the rectilinear type may be used with very minute stops, but cannot be recommended. For line work the definition must be such that the angles of two crossing lines show no spreading or filling at their intersection. Half-tone work does not make quite such stringent demands, but in order to make use of the differently shaped stops required, they must have a large aperture for at least a portion of the exposure; lenses for this work must also have very perfect corrections.

Wet plate process.

Process lenses require to be specially corrected, because they are always used for copying at close quarters; a lens that is corrected for distant objects will not be so well suited for objects placed at a distance of twice or three times the focus, moreover, as the wet plate process depends specially on the violet and ultra-violet rays, these lenses should be specially corrected for this end of the spectrum.

For three-colour work, lenses must be specially corrected for achromatism, as if they have only the ordinary type of photographic correction, there may be a difference of an inch between the foci of the different colours in a long focus lens (25 inches).

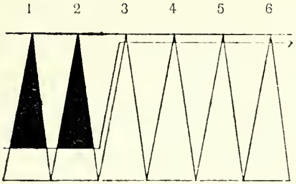
Prisms and mirrors.

Nothing has probably been more injurious to the quality of commercial photo-reproductions than the employment of bad quality mirrors and prisms used for reversing the image. There are many good lenses in use with mirrors and prisms which are so inferior that the whole advantage of the quality of the lens is lost. To produce a large flat surface optically perfect is one of the most difficult duties of the glass worker; no error should be allowed, that exceeds 1-100,000th of an inch—flat surfaces can now be produced which are within 1-1,000,000th inch. Some of the cheap so-called "optically worked" prisms and mirrors are scarcely equal to plate glass, and entirely ruin fine definition. The best rough test for the quality of a mirror or prism is to place it in front of a telescope having an aperture of about three inches, and view through it, the reflected image of a star upon a clear night, comparing it with the image of the same star seen direct.

The same remarks on the inferior surfaces found in many mirrors and prisms apply in equal force to light filters. It is not only necessary that such filters should be parallel, it is essential that their surfaces should be, as in the case of prisms, optically plane and of as high a quality. In using long focus lenses, particularly for copying, it is hopeless to expect the best results unless the light passes through surfaces that are made with the utmost degree of perfection.

The absorption of light by glass is a question of interest, as the glass used in the lenses and prisms for process work has an influence on their rapidity, but too much attention need not be given to the thickness of glass that the light passes through in an anastigmat, as this is small compared with the amount it has to pass through in the prism used in conjunction with it.

Diagram of the most suitable lens.



Maximum of qualities.
Degree required for Photo-mechanical work.

Figure 126.

1. Rapidity.
2. Depth of definition.
3. Quality of definition.
4. Angle of view.
5. Equality of illumination.
6. Absorption.

The height of the intermediate line marks the degree to which the qualities are required; the less "black" that appears, the less of that particular quality is essential.

Figure 126 illustrates the degree to which the various qualities are required for this work.

All the line blocks and half-tones illustrating this book have been produced by the Beck-Steinheil or Steinheil lenses. The photogravures in the "Edition de Luxe" were produced by a Beck-Steinheil Orthostigmat, No. 9, Series III., f/10, combined with a Beck-Harris Filter, Quality I.

BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION VI.

(1) Long focus lenses are the best for portraiture, for they give good modelling and perspective; brilliant definition is inartistic.

(2) The focus of a portrait lens, should be three times the longest side of the plate in use.

(3) A long focus single lens is excellent for large heads.

(4) A rapid lens stopped down is not usually as good as a slower lens.

(5) Various hints to amateurs are given.

(6) There are many interesting points on landscape and general work.

(7) Details of what makes a good landscape and what does not are given with an example.

(8) The best lens for landscape work is a long focus one.

(9) A narrow-angle picture is always more truthful than a wide-angle one.

(10) The influence of various properties discussed.

(11) Every hand camera lens should at least have fine central definition.

(12) The best lens, regardless of price, is the Orthostigmat (anastigmat), next the Biplanat.

(13) Great covering power with a short focus makes the Orthostigmat the best lens, as short focus entails depth of definition.

(14) A cheaper lens means some good qualities are sacrificed.

(15) For extra rapid work a very rapid lens is required, to allow for exposures of 1-100th to 1-1000th of a second, usually with a focal plane camera.

(16) For ordinary hand camera work a slower lens will do, to allow for exposures from 1-10th to 1-100th of a second.

(17) A rapid lens, even for this work is really best, as short exposures may be given in bad light.

(18) A biplanat, rectilinear, single or periscopic lens can be used with success if the aperture is not smaller than f/11

(19) Notes on exposures, focussing, scales and distances of objects

(20) For architectural work an exact transcript is required

(21) More than one focus of lens is a great advantage for this work

(22) All lenses for architectural work must be free from distortion

(23) A large angle of view is desirable

(24) Rapid lenses are the best

(25) For enlarging, a lens giving a flat field and critical definition should be chosen.

(26) Equality of illumination is essential

(27) For photo-mechanical work, the finest corrections in every direction are required.

(28) The best lens is the only one to choose for this work.

SECTION VII.

LENSES FOR SPECIAL WORK.

Special work.

Beyond the usual practical applications of photography, there exist a number of more or less difficult branches of work which need special lenses, that is, lenses which do not find their way in the ordinary course into the photographer's outfit.

There are, however, some included in this section which ought to be found in a photographer's outfit if it is to be complete, such as the telephoto lens and, perhaps, a supplementary lens or two for altering the focus of the primary one. It is with the idea of indicating in outline certain unusual characteristics that their consideration is dealt with separately.

They include—

Lenses for special work.

(1) Telephoto lenses and attachments.
(2) Supplementary lenses (magnifiers).
(3) Cinematograph lenses.
(4) Stereoscopic lenses.
(5) Condensers and lantern lenses.

The first, opening up as it does such a large field of most interesting work for the photographer, is fully discussed.

TELEPHOTO LENSES.

Telephoto lenses and attachments.

An interesting forecast of the popularity of this special lens is to be found in Trail Taylor's "Photographic Optics." It runs—

> In the early days of photographic lenses there was one brought out known as the "orthoscopic" which claimed to be free from distortion and to possess other salient features. These advantages proved to be overstated; it did possess, however, certain characteristics,

of which the writer went on to say—

> The orthoscopic lens when subjected to certain modifications of construction may yet, possibly, be found to be the lens of the future.

This lens (figure 127) consists of an achromatic meniscus (A) similar to the front lens of a Petzval portrait combination, while behind it and beyond the diaphragm is placed an achromatic concave or negative lens (B), usually of smaller size than the front. This negative back lens materially lengthens the focus of the whole. From the foregoing rough description it will be noticed that the same principle has unconsciously been employed as that used in the telephoto system proper, the front lens (A) answering to the ordinary lens, the back (B) corresponding with the negative element or telephoto attachment. With reference to this Trail Taylor, writing some 10 years ago, goes on to say—

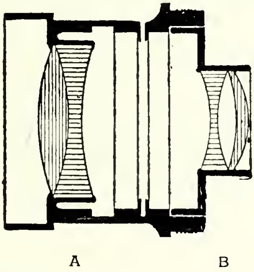


Figure 127.

The orthoscopic lens.

> A special virtue possessed by the Orthoscopic lens and no other, consists in the ability of obtaining with it

Quotations from Trail Taylor.

larger sized images in the negative with a given extension of camera, than can be obtained by any other lens extant. The focus of a lens is measured from its focal centre, and while this in a single lens is rather nearer the ground glass than the lens itself, it is in the orthoscopic combination, as just stated, outside the lens entirely; so that, with a given length of camera, a much larger image of an object can be obtained by the orthoscopic lens than by any other. This property is of great value.

This quotation is an almost prophetic forecast of the telephoto lens.

Variable foci.

There is much misapprehension as to the principle of the telephoto lens. It is essentially nothing more than a long focus lens of peculiar construction. There is in addition a further advantage, it is not merely one single long focus lens, but a series, inasmuch as an adjustment is supplied whereby the focus can be varied at will.

The principles upon which the telephoto lens is constructed can be explained in quite an elementary manner.

Explanation of the construction of the lens.

Hitherto it has been assumed that the back equivalent or nodal plane is situated in the centre, or not far from, the lens. This is nearly true, in the symmetrical form of lens, but by no means is it always the case, for even in such a primitive form as the uncorrected single lens, its position varies according to the shape or curves of the surfaces.

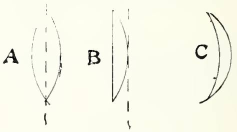


Figure 128.

The position of the optical centre in various lenses.

Figure 128 shows three lenses—in A, a double convex lens, the optical centre lies in the middle of the lens; in B, a plano convex lens, it lies on the front surface; and in C, a meniscus lens, it is completely outside the lens itself.

Effect of the position of the optical centre upon the camera extension.

Now consider two lenses of identically the same equivalent focus, one a double convex constructed like A and the other a meniscus as C. These lenses will produce pictures in which all the objects are identically the same cize, and yet, owing to the position of the optical centre in the two cases, the double sonvex lens A will be further from the plate than the meniscus lens C.

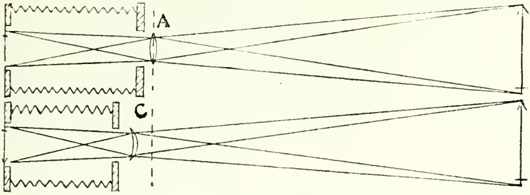


Figure 129.

Figure 129 will make this clearer, and shows that as a consequence the camera extension for a lens of a construction similar to C will be less than one constructed like A.

The variation in the position of the optical centre in the case of a single lens is never very marked, but the analogy is useful in considering the telephoto lens, for this is a combination of lenses specially designed so that its optical centre is a great distance in front of the lens itself, as the diagram (figure 130) shows.

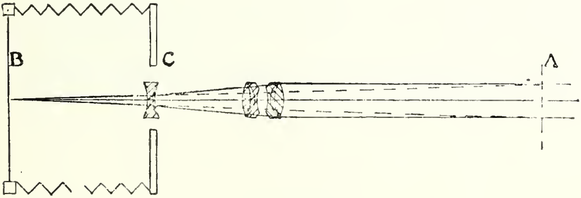


Figure 130.

A is the position of the back equivalent plane, B represents the plane where the picture is

The position of the optical centre in the telephoto lens.

formed, the distance A B is therefore, as explained, the equivalent focus. C is the plane in which the camera front lies, and C B represents the camera extension necessary to use a telephoto lens of a focus equal to A B. In order to obtain the same result with an ordinary lens a camera extension equal to A B would be required.

Thus with a short camera extension a lens of long focus can be used.

Negative lenses.

A negative or concave lens, on the other hand, can by itself produce no picture of any object on the ground glass, it is possessed of a virtual focus only. This may be explained by figure 131.

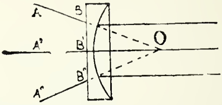


Figure 131.

If a piece of black card with three small holes in it is placed in front of a negative or concave lens and light coming from any distant source is allowed to fall on it, three pencils of light, which pass through the holes, will be bent outwards as BA, B'A' and B''A'', by the negative lens, and will appear in consequence as if they had come from a point O, which is called the virtual focus of a negative or concave lens.

The virtual focus.

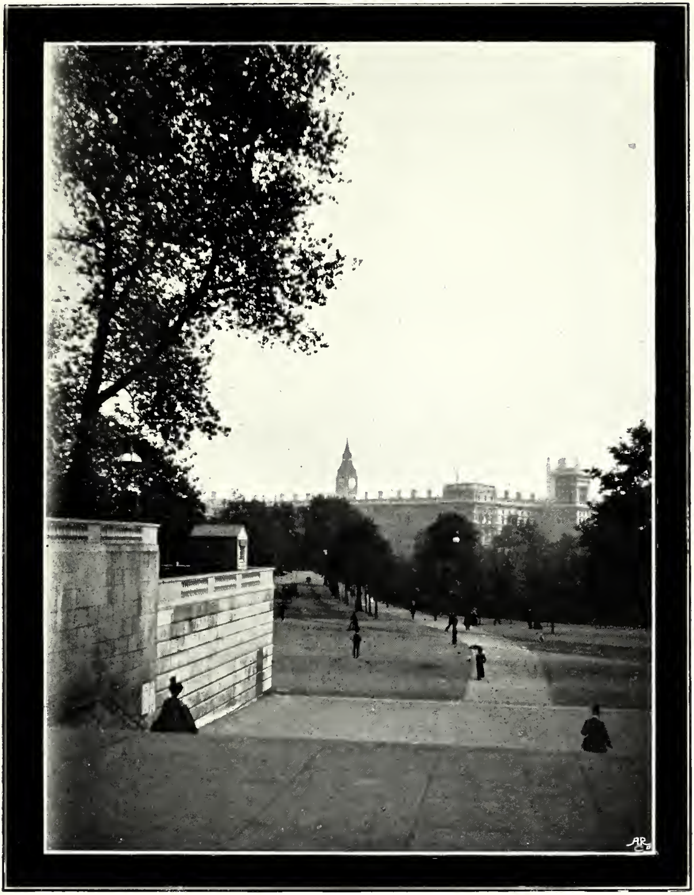
A virtual or imaginary image is produced: it is not real, and could not in consequence be used for photography, but by utilizing the peculiar properties of a negative lens, and combining a particular form with an ordinary positive lens as used on the camera, the telephoto lens is constructed.

This lens possesses the curious property of having its optical centre a long way in front of the front surface of the lens itself (figure 130).

Every photographer possesses a positive photographic lens, and provided this is of good

See page 240.

PLATE XL.—"BIG BEN."



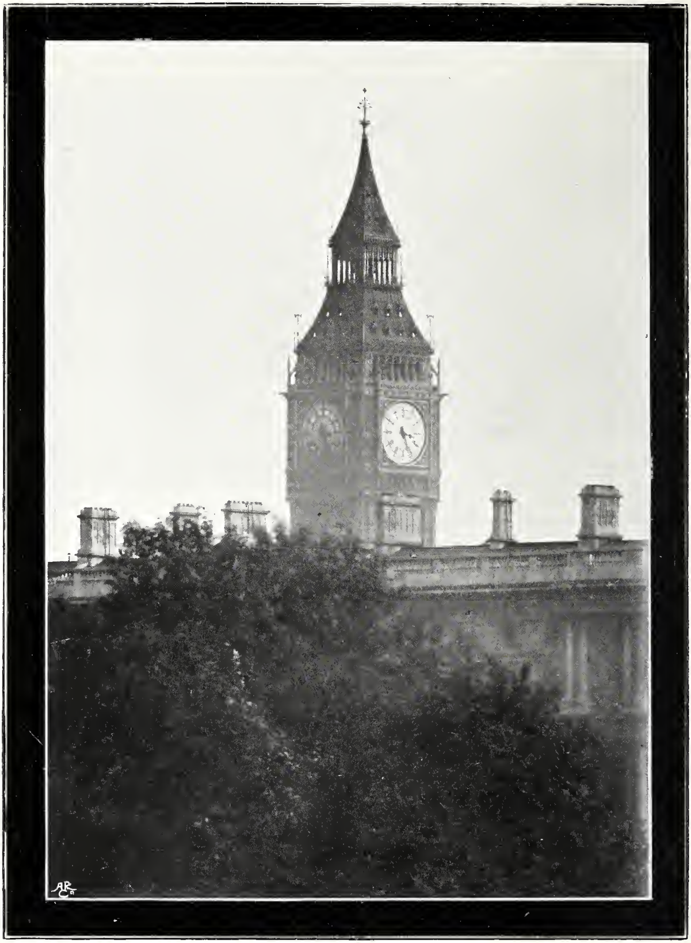
Negative by *W. H. Wilkins.*

From a photograph taken with a No. 3 Beck-Steinheil Orthostigmat, f/6·3, focus $7\frac{1}{8}$ inches.

PHOTOGRAPHIC LENSES.

See page 240.

PLATE XLI.—“Big Ben.”



Negative by *W. H. Wilkins.*

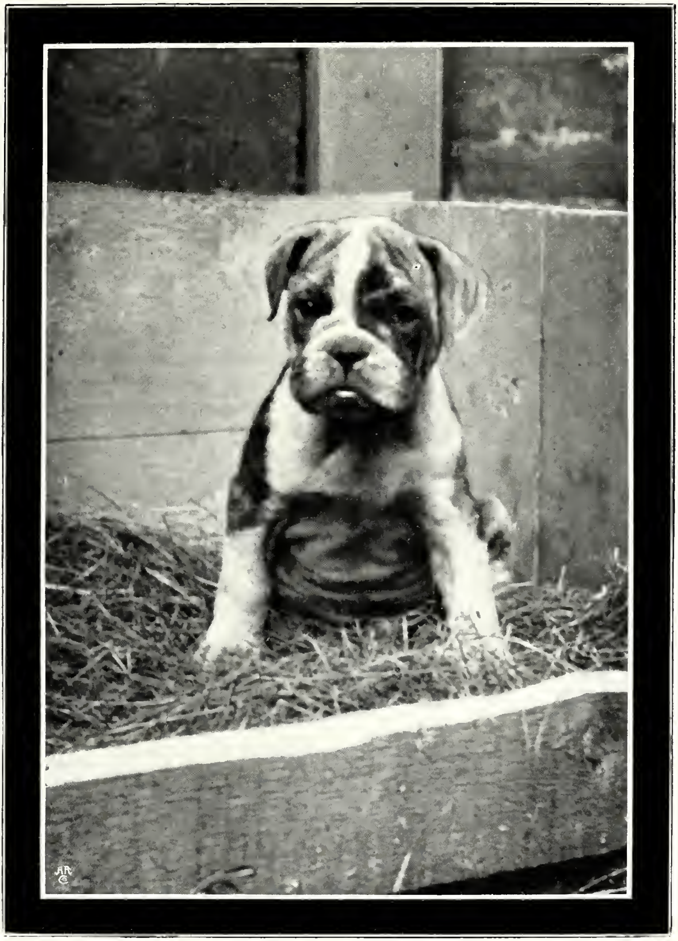
From a telephotograph taken with a Standard Power Attachment and a No. 5 Beck-Steinheil Orthostigmat. Magnification 8 times.

PHOTOGRAPHIC LENSES

See page 250.

PLATE XLII.

"OTHO."



Negative by *Miss H. Beck.*
From a photograph taken with a No. 2 Frena Beck Autograph R.R. Lens, f/8, being an example of focussing by the Frena system of magnifiers.

PHOTOGRAPHIC LENSES.

position that the light is brought by the positive lens Y to its normal focus at O. Thus it is evident that by altering the distance between the two lenses of a telephoto system a great number of different foci are obtainable. The function of the negative element is to take a portion of the picture produced by the ordinary photographic lens (the positive element) and to magnify it. The amount of magnification may be varied at will.

The function of the negative lens.

PROPERTIES OF THE TELEPHOTO LENS.

Properties of the telephoto lens.

The foregoing is intended as a simple description of this somewhat complex lens. The following pages will explain some of the properties which affect its use and application.

Size of the field illuminated.

The diameter of the size of the field varies directly with the magnification (or length of focus) of the telephoto system, although it is slightly decreased by the use of a small stop.

In figure 135 is represented a telephoto lens, with which the image can be focussed sharply at different distances behind the system, namely at a″, a′ and a. For instance, at a″ the magnification is small, say twice, and the circle (diameter) is XX′, while at a′ the magnification is increased to four times, and the diameter is now YY′ and is greater than XX′. In the third case the magnification is eight times and the circle of illumination has a diameter equal to ZZ′, much larger than in either of the preceding cases. So that the area of the field

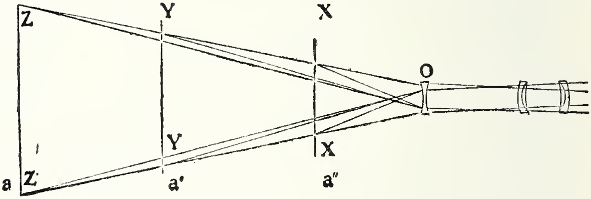


Figure 135.

varies directly with the magnification (*though all the time the angle of view XOX', YOY' and ZOZ' is the same*).

Effect of a small circle of illumination.

It has been thought necessary to mention this fact because when using a telephoto lens with only a low magnification, the ground glass will have a circle of light on it representing the view, while the corners will be black.

Such an appearance might lead those unaccustomed to the use of the lens to suppose that their manipulation was defective, but when a small or low magnification only is required, as is occasionally the case, it is impossible without a lens specially designed for low power work (see low power elements) to cover the whole plate. An adjustment to the telephoto lens increasing the magnification will rapidly enlarge the diameter of the field of view, spreading the image over the whole surface.

Area of circle of illumination with different lenses.

An example taken from the table at the end of this pamphlet may make the point clear.

A $\frac{1}{4}$-plate telephoto lens when magnifying three times (i.e., when an object is depicted three times as large as by the positive alone) illuminates sharply a circle of view $2\frac{1}{2}$ inches in diameter. (*This is only in the case of our Standard power, the Low power would give a $5\frac{1}{2}$-inch circle of sharply defined picture at a similar magnification*). This would not fill the whole of a $\frac{1}{4}$-plate, but when the magnifying power is increased to ten times, the circle of view illuminated becomes $9\frac{1}{2}$ inches in diameter, which would not only cover a $\frac{1}{4}$-plate, but even a $\frac{1}{2}$-plate.

It often happens that this "special" lens is used for photographing some particular detail, such as the capital of a column or a bird's nest; for this work a low magnification is required, the corners will not be illuminated, but the object of interest will be in the centre of the illuminated portion, so that it is of no account.

Table of the diameter of the field necessary for various plates.

The following table gives the diameters of the circle of illumination necessary to cover plates of different sizes.

Plate in use.	Circle of View required in inches.	Plate in use.	Circle of View required in inches.
$4\frac{1}{4} \times 3\frac{1}{4}$ - -	$5\frac{4}{10}$	$8\frac{1}{2} \times 6\frac{1}{2}$ - -	$10\frac{7}{10}$
5×4 - -	$6\frac{4}{10}$	10×8 - -	$12\frac{3}{4}$
$6\frac{1}{2} \times 4\frac{3}{4}$ - -	8	12×10 - -	$15\frac{1}{2}$
7×5 - -	$8\frac{6}{10}$		

The angle of view included in the circle of the field of view does not vary with the magnification. It is the size of the circle of illumination only that varies.

The angle of view is constant.

To emphasize the importance of the above, it must be understood that, if a certain amount of the landscape is included within the complete circle of view, an alteration of the magnifying power will increase or decrease the size of the picture and the circle of illumination with it, but will not alter the amount of the landscape in the whole field. It must, however, be borne in mind that when the plate in use is smaller than the field of view as in figure 136A, though the whole view is portrayed, the plate is only receiving a portion of it.

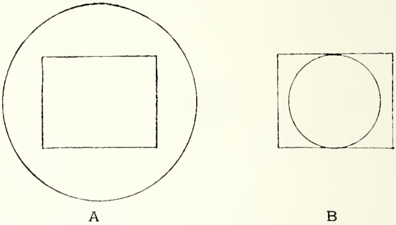


Figure 136.

In figure 136B the plate is receiving the whole. The actual extent of the landscape included in the two figures is the same, only the scale on which they are rendered is different.

Equality of illumination.

Equality of illumination is increased by stopping down the positive.

If a lens illuminates the edges of the field of view as brilliantly as the centre, then the equality of illumination is perfect, but if the light gradually fades away into total blackness from near the centre to the edge, the reverse is the case.

The field of view of a telephoto lens somewhat shades off in this way near the extreme margin of the field. This is due to the distance of the lenses of the system from one another. It is, however, not very appreciable if the positive lens is one of the modern orthostigmatic or anastigmatic type.* It may be considered as a general principle that a positive photographic lens, which is designed only to cover the plate for which it is constructed, is not so suitable as one which is capable of covering a much larger plate, as, for instance, the orthostigmats listed at the end of this book.

The effect of stopping down.

The stopping down of the positive increases the equality of the illumination, but this must not be carried too far (see Rapidity).

Rapidity.

Therefore, for successful telephotographic work, a positive giving a great equality of illumination combined with rapidity is the best.

The rapidity of a telephoto lens is much less than that of the positive alone, and varies inversely with the magnification.

When an ordinary photographic lens is converted temporarily into a telephoto lens by the addition of a telephoto attachment, the focus of the lens has been altered, but not the size of the aperture, and consequently, the effective aperture of the Iris diaphragm remaining the same and the focus being increased, the rapidity will have been reduced.

The adjustment which alters the focus of a telephoto lens is engraved with a scale. This scale is divided to show the magnification or the increased size of the image over that produced by the positive lens alone. On the Beck-Steinheil Telephoto Attachments figures 3, 5, 8, 10, etc., are engraved, which represent the increased size of the image as compared with that of the positive alone.

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* A low power element is always nearer to the positive than one of higher power; it is also of greater diameter; consequently, with this combination the illumination is the most perfect.

To find the effective aperture or rapidity of a telephoto lens in terms of the focus (f) :—

Rule for finding the aperture of a telephoto lens.

Multiply the aperture of the positive by the magnification in use. Thus, if the diaphragm of the positive be set at an aperture of f/8 and a magnification of 4 be in use, the resultant aperture of the whole system in terms of the focus will be f/32, and if an exposure of 4 seconds was correct with the positive alone, 64 seconds must be given for the telephoto lens.

To sum up

(*a*) To find the aperture (therefore the rapidity) :—Multiply the aperture of the positive by the magnification.

(*b*) To find the requisite exposure :—Multiply the exposure required by the positive alone by the square of the magnification.

Diffraction.

Theoretically an aperture not smaller than f/72 should be used in the combined lens, that is, if 8 magnifications are in use the position must be f/8 and not smaller, else diffraction may be introduced.

The following table will give at a glance the largest magnification that should theoretically be used with different apertures.

Aperture.	Maximum magnifying power.	Aperture.	Maximum magnifying power.
f/4	18	f/16	4½
f/6	12	f/22	3¼
f/8	9	f/32	2¼
f/11	6½		

This further emphasizes the necessity of having a good rapid positive. A positive with nominally a very large aperture, but without equality of illumination and first-class corrections, will have to be stopped down before definition is obtained, and in this case it is no better than a slower lens which does not need stopping down.

In actual practice the question of diffraction is not of such great importance as theory would indicate, a stop *as small as f/250 can be used, and the definition thus sacrificed, is replaced by increased depth of focus (see page 236).*

Loss of light by reflection.

A telephoto lens of the Beck-Steinheil type has the least possible number of outside surfaces, namely, 2, and loss of light by reflection may be neglected. The positive should have as few outside surfaces to scatter the light as possible.

Most suitable attachment for rapid and slow lenses.

It may also be pointed out from the foregoing that for a positive lens of great rapidity an attachment of high power is suitable, while for a positive of low rapidity an attachment of low power is most suitable.

Depth of focus.

The depth of focus of a telephoto lens is dependent on the aperture actually in use; if a positive with an aperture of f/6 is used with a magnifying power of 4 it will have one-fourth the depth of focus for distant objects that is possessed by the positive alone; if 6, one-sixth and so on; the depth can be increased by stopping down the original positive in the usual manner.

Distortion.

The distortion present in a telephoto lens of the Beck-Steinheil type is a negligible quantity, provided the negative element is combined with a positive, in which there is no distortion.

In a lens of the single type there is invariably distortion present, which renders straight lines in the photograph curved when they lie at the edge of the field. There is no distortion present in the case of a good doublet lens. The negative lens itself is usually not free from this defect, but if the formula has been carefully calculated, and the lens is suitably adjusted, it is so slight that it may be disregarded.*

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* There is very little doubt that in telephotography, just as in any other comparatively little followed branch of work, the tendency to run to extremes is disastrous to beginners, and results in disappointment owing to poor pictures. It is most important to use the smallest magnification possible, and in general 3 to 4½ will be ample, and the difficulties will be no greater than in the use of the ordinary photographic lens. Where price is not of great importance the low power magnifying element will give the most satisfactory results and the circle of illumination is very large.

DESCRIPTION OF THE TELEPHOTO LENS AND ITS ADJUSTMENTS.

A brief description of the appearance of the lens may be useful. The Beck-Steinheil Telephoto Lens[*] has been taken for illustration.

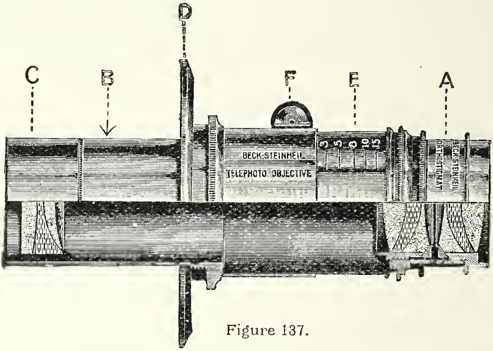

Figure 137.

The telephoto lens and the telephoto attachment.

A distinction has been carefully preserved between the telephoto lens and the telephoto attachment. In figure 137 a complete telephoto lens is shown consisting of an ordinary photographic lens A screwed into the telephoto attachment B. The latter consists of a suitable negative lens C, mounted at the end of a brass tube which screws into the flange D: this flange is fixed in the ordinary way to the camera front, and is of such a size that it will allow of the use of the positive lens A alone, or the complete system, without the addition of an adapter.

By rotating the milled head F the distance between the positive A and the negative B can be varied at will.

If the distance be varied in this way the focus of the system will be altered, as has been pointed out, and therefore the magnification. The tube E is engraved with a scale 3, 5, 8, 10, 15, according to the attachment, as shown in figure 137. These numerals represent the magnifying power, or the number of times the image produced by the telephoto lens, is larger than that which would be produced by the positive alone. The milled head F can be used to finally adjust the focus if the exact magnification is not of importance.

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[*] This lens is obtainable in 3 powers, Standard, High and Low power· that illustrated is the Standard power.

The combination illustrated in figure 137 is a Beck-Steinheil Orthostigmat Series I., f/6·3, and a Beck-Steinheil S.P. triple cemented negative lens or attachment mounted in a brass tube, with a rack and pinion focussing motion and engraved with the magnifications. This is the most useful combination and fulfils all the conditions laid down as essential for successful telephotography; it is recommended for:—

Applications.

(*a*) Natural history work.
(*b*) Architecture.
(*c*) Distant landscape and marine work.
(*d*) Mountain scenery.
(*e*) Astronomy.

For the special high speed work referred to on page 242, it may be found more advisable to substitute an Extra Rapid Autograph Lens working at f/4 or Biplanat for the Orthostigmat, when the combination can be used for

(*a*) Portrait work.
(*b*) Difficult medical studies.

NOTES ON THE APPLICATION AND USE OF THE LENS.

Reason for its use.

It may be asked, why should a telephoto lens be used when a small picture might be taken, the required portion of which can subsequently be greatly enlarged? No doubt such a plan could be adopted, but it would be found that great loss of definition would be the result. A photographic negative consists of a sedimentation of small silver granules, and in enlarging a small picture these granules are also correspondingly enlarged, producing, except in the case of very moderate magnification, a coarse appearance which destroys definition. It is to avoid this result that a telephoto lens is employed.

EXPOSURE.

Exposure.

Before considering the actual practical applications of the telephoto lens, a few remarks on exposure may be interesting. The rule already referred to must be borne in mind, namely, that the correct exposure may be ascertained by multiplying that required by the positive alone, by the square of the magnification.

Telephoto pictures that are reproduced in this book.

All the telephotographs, with the exception of one Swiss view, which are reproduced in this book have been given exposures on this basis, and they are examples of English work where all the disadvantages of climate, etc., had to be overcome. They are not taken in the dry and clear atmosphere of America, where a leaning towards under-exposure might be a positive advantage. Some writers have criticised the method given for arriving at the correct exposure, stating that it tends towards over-exposure, and it is in order to impress on the beginner in this branch of work the necessity of a full exposure that these few remarks are included.

The correct exposure for the positive alone.

The first point to consider is, what would be the correct exposure if the positive were used without the telephoto attachment? It is well known that there is much latitude in this respect with good plates or films. A series of five photographs were taken at the following exposures—1-5th, 1-10th, 1-20th, 1-40th, 1-80th of a second on the same brand of film and at the same aperture with a shutter (Frena principle) which, under every condition, gives the same relative exposures and is perfectly reliable, because, even if the initial exposure be inaccurate, all the succeeding ones are exactly half the previous. The results of those tests showed printable results at every one of the exposures, and with careful development there was little to choose between them, though the extremes were slightly over and under-exposed. The correct exposure as far as could be judged was 1-30th of a second, but 1-80th gave a worse result than 1-5th. This is what might have been expected, for the shortening of the exposure intensifies the high-lights and omits the details in the shadows, while over-exposure levels down all contrasts but preserves the details. In telephotography it is the details that are required; for an object that, on a small scale, might appear sufficiently portrayed with a short exposure, upon a large scale, would require more detail to be shown. Suppose a magnification of 10 to be used, the correct exposure would have to be multiplied by 100 giving 3½ seconds, and it is quite probable that 20 seconds or more would have given some result, as also would 1¼ seconds. Now, it is almost certain that the correct exposure for the positive will be over-estimated, as few but those accustomed to the constant use of rapid shutters give the minimum exposures. One-tenth of a second would probably have been selected in place of 1-30th, in which case 10 seconds works out to be the exposure required, or *three* times that which is correct. When this is done it is not the fault of the rule that the picture is over-exposed, but of the worker in making the original estimate of the exposure. The cure is not to alter a correct rule, but to obtain a more accurate knowledge of exposures.

Effect of under and over-exposure.

There is another aspect to the question that is worth considering. It is distance that is being dealt with in telephotography. In photographing an open landscape with objects stretching away for a mile or more, as in plate XXXIII. the exposure should be regulated, not to bring out the foreground or the heavy

Effect of distance on exposure.

foliage to the left, but the distance, and should in consequence be much shorter than is usual for a landscape with heavy foliage. The subject illustrated had an exposure of 1-5th of a second at f/32, Beck-Harris screen, Isolar plates; whereas to have fully rendered the foreground an exposure of 1 second would have been better. Now, the exposure for plate XXXII. was calculated not on the exposure necessary for a proper rendering of the foreground and heavy foliage which is scarcely included, but on the actual exposure given for plate XXXIII., which is too short for anything but the distance. If this had not been done, five times too much exposure would have been given, and once again theory would have been falsely accused. It must always be remembered that telephotography is concerned with distance.

ON STOPPING DOWN.

On stopping down.

Uncertainty of the diffraction theory.

Earlier on it was suggested that the telephoto lens should not be stopped down below f/72, according to theory, whereas practice tells a different tale. The theory of diffraction is dependent on the wave theory of light, and, until some more definite knowledge is forthcoming as to the ultimate nature of light, deductions from this theory must be accepted with caution.

Plate XXXV. is included here as an example of the results following on the use of f/240; very poor definition would have been expected, whereas the definition is good. From a considerable experience of telephoto lenses and telephoto work, it seems that the appearance of diffraction is of much less importance when the aperture of the lens system is of some considerable size, however small the actual value of the focal aperture may be. In the case in point the aperture of the system employed, when stopped down to f/240, measured a $\frac{1}{4}$-inch across — a sufficiently large

Focal value of the aperture.

aperture to admit of the passage of a large bundle of light without interference. If the aperture of f/240 had been employed on the positive alone it would have measured only 1-35 inch across, and diffraction would undoubtedly have injured the definition. For telephoto work in the field it seems only necessary to have a clear aperture of not less than a ¼-inch in the Iris diaphragm of the positive, and it will not be found to matter what its focal value is. These remarks are simply based on practical experience, and do not profess to put forth any new theory.

Natural history.

Some of the beautiful work which has appeared from time to time illustrative of wild life, as it is seen in nature, was rendered possible by the introduction of the telephoto lens. The study of timid creatures has been rendered easier by the advantages which it affords. To approach as near a bird as is necessary with ordinary apparatus to obtain anything but a diminutive picture is almost an impossibility, but, on the other hand, to get the same sized picture with a telephoto lens, the distance may be 4, 8 or 10 times as great.

Suppose, for instance, it is required to photograph a starling on the edge of the hole in which its nest is built. To obtain a sufficiently large image with a 9 in. lens and a half-plate camera the instrument cannot be more than 3 feet away. A telephoto attachment fitted to the same lens, and adjusted to give a magnification of 8, would enable the photographer to retreat with his apparatus to a distance of 24 feet and produce a similar picture. The value of this extra distance can hardly be overestimated in photographing natural history subjects, where the close proximity of a camera is likely to disturb the object.

Another advantage is the better perspective given—to quote an example in the writer's experience—the photograph of a tern's nest among the sand and gravel was rendered much more lifelike by the use of a long focus lens than would have been the case if an ordinary photographic lens had been used. The latter, by giving undue prominence to the eggs by dwarfing the surroundings, would misrepresent nature and give a lack of proportion to the picture.

Architectural work.

Perhaps in no other branch of pictorial or technical photography does the value of the telephoto lens become more apparent than in architectural work. There are numerous delicate pieces of carving, curious small windows, gargoyles, etc., which appear insignificant when photographed under ordinary conditions, but which when selected and reproduced for themselves become at once objects of beauty and interest. It was a common practice in olden days for the carving on the capitals of columns in the great churches to be presented by private people who had been miraculously cured, and when this was the case the carving was often symbolic of the affliction. The famous "Corn and Toothache" capital is an example. This appears of little interest when photographed in the ordinary way, but, when taken with a telephoto lens, can be well displayed, without being engulfed in a mass of extraneous detail. The study of the ornamentation and fine carving on windows and columns is an important means of tracing the variations of architecture through Norman and Early English up to the Perpendicular style. There are many examples of interesting carvings quite unapproachable without the aid of scaffolding, and therefore up till now overlooked, which are brought within the range of the architectural photographer with a telephoto attachment.

The question of what magnification should be used for architectural detail is a difficult one to answer. It is often possible to place the camera in several positions all at different distances from the selected object, and by the adjustment which varies the focus of the telephoto lens to obtain the same size picture in each instance. Other things being equal, a magnification of not more than 3 or 4 is recommended; at the same time, if the subject is much above the level of the camera, a better effect will be obtained by taking the camera to a greater distance and using a higher magnification. It would not be necessary then to point the camera upwards at such a great angle. It will occur to the reader that as his eyes are not situated in the top of his head, views looking upwards will not appear as natural as those taken at a less angle.

Examples of different kinds of architectural work.

Three examples of architectural work under differing conditions are here illustrated.

Plates XXXIV. and XXXV. are photographs of St. Albans from Verulam Woods, at a distance of a mile and a half—they are of special interest, because from no nearer position can a view be taken of this abbey church showing its entire length and its wonderful Norman tower dominating the surrounding country. This verges almost into landscape photography. The next plates, XXXVI. and XXXVII., are examples of closer work. The telephoto picture represents one of the west towers of Durham, the inspiration of those lines from Scott that are carved on the bridge over the Wear:—

" Thy three grey towers, half church of God,
" Half castle 'gainst the Scot."

It is singled out to show the wonderful detail of the decorated period of ecclesiastical architecture.

Plates XXXVIII. and XXXIX. form fair examples of interior work requiring long exposure, and need no explanation. Attention might be drawn to the excellent definition although the aperture was large. The fine masonry joints are clearly visible though less than $\frac{1}{2}$ inch across. This points to an application to which the lens lends itself: there are architects and borough surveyors who may require records of defective portions of buildings only otherwise obtainable by the aid of scaffolding.

Distant landscapes.

The many ways in which this lens can be made of use in landscape or distant mountain work* will suggest themselves to the photographer. The difficulty of obtaining convincing photographs of mountain scenery with the ordinary camera is due to the dwarfing of the distance and the exaggeration of the foreground. The telephoto lens gives a more proportionate rendering. The foreground is omitted or diminished in size and the distance magnified and brought nearer.

Plates XXXII. and XXXIII. have already been referred to when discussing exposure, but they form a good example of a picture that would have been lost but for the telephoto lens, and one that possesses distinctly pleasing properties. The bright and slightly diffused distance throws up the old mill in its darker hollow by the water in a manner that is most effective, and the shocks of corn over two miles away seem appropriate to the spirit of the mill.

Rapidity of exposure is of little moment in landscape work, and therefore the prolonged exposure required with the telephoto system may be made without inconvenience.

Seascapes.

Besides those purposes already mentioned, the possibilities of the telephoto lens for work on the sea are numerous. The intense light is a help in that it reduces the exposure necessary; at the same time there goes with this advantage a certain disadvantage, inasmuch as the atmosphere in contact with the water is more liable to be misty and "quivering" than is the case on land.

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* The two photogravures facing the beginning of this section in the Edition de Luxe, illustrate this point; the telephoto is much the better picture. These are reproduced as half-tones in the cheap edition Plate.

The quality of the definition of a telephoto lens is above everything dependent upon the clearness of the air between the object and the camera, and always use a spectrum filter if possible.

Portraiture.

In portraiture the use of the telephoto lens is more limited, speed is a *sine qua non.* It is usually conceded that the most successful portraits are taken with the lenses of the longest foci; but the cost of a long focus portrait lens is so prohibitive that the average amateur has to content himself with one of moderate focus. In this case the addition of a telephoto element will place in the hands of the amateur a battery of long focus lenses. Provided the work is confined to low magnifications, the aperture will not be so small as to necessitate excessive exposures while the focus will be sufficiently increased to produce a pleasing perspective.

Medical studies.

Medical work may be considered as a branch of portraiture and this lens is often of special use. The necessity of placing the camera uncomfortably near the patient is done away with, and the perspective is improved.

A parlour game.

Those who are in search of some new line of experimental work might make a collection of photographs of their friends' eyes, possible with the aid of this lens; it will give much pleasure and amusement if names are to be found for each "eye" by those who are acquainted with their owners, it might take the place of book parties and other social pastimes.

War pictures.

A reference to the application of the telephoto lens in war ought to be made. Many successful distant photographs were obtained during the South African campaign, since the intense light of the veldt allowed of high magnifications and short exposures.

Balloon pictures.

Views from balloons for survey or military purposes are of far greater service if a telephoto lens is employed, giving as it does a larger picture of distant objects.

Other applications.

The branches of work to which the telephoto lens can be successfully applied could be summed up under one head: Subjects too far off to be photographed with the ordinary positive.

INSTANTANEOUS TELEPHOTOGRAPHY.

Possibility of instantaneous telephotography.

The question as to the capabilities of the telephoto lens for instantaneous work has often been discussed. Under suitable conditions it may be used for snap-shots, but with a low power element and magnification only. With a view to making this very interesting use of the lens practicable, the lower power system (Beck-Steinheil attachments) was introduced, since it gives a very large circle of illumination with only a comparatively low power; so that the plate can be covered easily without the necessity of a great magnification. To take an example from the table at the end of this book, if a magnification of 3 is all that is required with the standard attachment and a $\frac{1}{2}$-plate lens, a circle of only $4\frac{1}{4}$ inches is given, which will not nearly illuminate a $\frac{1}{2}$-plate, whereas with the low power attachment and a similar magnification a circle of illumination of more than $6\frac{1}{2}$ inches is the result, and a $\frac{1}{2}$-plate will be almost covered. The advantage of this is apparent when it is remembered that a low power is the only magnification possible for instantaneous work, and at the same time great covering power is necessary. The high power and standard power attachments do not give this covering power with low magnifications, as will be noticed by reference to the table at the end.

With a good positive and the low power attachment, instantaneous exposures can be given; but it is important to remember that a less rapid speed must be employed than if the positive was used alone.

It should also be remembered that a focal plane shutter* has advantages for such a purpose because it allows a large quantity of light to pass through the lens with a given speed of exposure.

In bright sunlight fully exposed negatives can be obtained with exposures of 1-10th to 1-100th of a second with a magnification of 3 or 4, and in moderate light or for dark subjects ½ to 1-10th may be frequently given.

Illustrative plate.

The class of work that is made possible by instantaneous or perhaps more correctly "short exposure" telephotography, is illustrated by plate XLIV., the subject being a deer photographed under adverse circumstances.

NOTES ON THE USE OF THE TELEPHOTO LENS.

To obtain the best possible results, the camera should possess the following :—

(*a*) Great rigidity.
(*b*) Long extension.
(*c*) Considerable rising front.
(*d*) Preferably square bellows.
(*e*) Firm tripod attachment.
(*f*) Considerable swing-back.
(*g*) Isochromatic screen.†

Features of the apparatus.

Anyone possessing a camera which has not all the above points need not consider telephotography beyond him; first-rate results may be obtained, for instance, with a ½-plate camera having only 14 inches extension, conical bellows and a not particularly rigid front, but more care will have to be taken to guard against vibration during exposure, than would be necessary with a more solid camera.

A camera having the seven points enumerated above will go a long way towards making telephotography in any branch easy and certain. If an extension up to 24 inches on a ½-plate is used, the camera must be very rigid to prevent vibration. Vibration is the great enemy of successful telephotography, but if the apparatus is carefully chosen for the work, it may be satisfactorily avoided. The question of extension is one of importance only in so far as it governs the amount of magnification possible (a high magnification, a long extension). The magnifying power which will be most used depends to a very large extent on the class of work undertaken. Mountain, sea and landscape work often require high magnifications, while architectural work and portraiture seldom need more than 3 or 4 diameters. It is well, however, to have a camera with as much extension as possible. The camera should be provided with a swing-back with a considerable range of adjustment and a square, in preference to a taper bellows, though the latter is more portable. If the lens portion is the fixed part of the camera and the focussing is done by the screen, it is to be preferred.*

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* The most efficient form of shutter.

† The Beck-Harris special spectrum filter.

Camera extension.

The tripod.

Too much stress cannot be placed on the necessity of a thoroughly rigid tripod, for the advantage gained by the steadiness of the camera itself may be entirely sacrificed if the tripod be too slight, and the larger the tripod head the better. Some recommend in addition a strong tilting table fixed to the tripod in place of the usual head. This may be made to offer more support to the camera itself, and counteract any tendency to springiness when the camera is much extended. It also allows of alteration in the inclination of the camera without interfering with the position of the tripod legs.

Square model.

The camera most suitable for telephotography is the old form square model double extension.

At the same time any good instrument may be made to do excellent work, and while pointing out the most suitable form of camera, it must not be supposed that it is the only one with which successful work can be done.

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* A very useful accessory, for supporting the lens itself, upon a light camera is the "Bipod."

Focussing.

Where it is essential that the magnification should be a definite amount, the focussing must be done by the rack and pinion on the camera in the ordinary manner; but it will be found that although there is only one plane, which gives an absolutely sharp picture on the ground glass, there is some difficulty in finding it by this means, as the focus is so long and the angle of the bundle of rays so small that the picture appears almost sharp for a considerable distance, on both sides of the plane of perfect definition.

The usual method of focussing, where the exact magnification is not of primary importance, is to make use of the rack and pinion on the lens mount, after the size and focus has been roughly estimated.

By this means it is easier to be certain that the best possible focus has been obtained.

It has been mentioned previously that the rapidity of a telephoto lens is low. The image, therefore, is not brilliant on the ground glass, and difficulty of focussing is increased. The use of an achromatic focussing glass will be found a great help, and it dispenses with the use of a dark cloth.

Careful focussing is an essential for success in telephotography.

When the positive is of good quality focussing should always be carried out at full aperture, even though the lens is to be stopped down, finally for taking the photograph.

Most suitable magnifying power.

The highest magnifications may be used for seascape, mountain, and landscape work, where the light is usually very good. It is not an uncommon thing to give with an ordinary photographic lens on a rapid plate an exposure of 1-200th of a second at the seaside, to obtain the same result with a magnifying power of 10, an exposure of only half a second would be necessary, and the increased length of exposure is no drawback, nevertheless it is a wise rule to use the lowest magnification that will give a suitable picture.

Interior exposures.

If a photograph is to be taken inside a cathedral, where the correct exposure is, say, 3 minutes for the positive alone, a magnification of 10 would be out of the question, an exposure of 5 hours being required to get the same result. Consequently, from the point of view of exposures only, high magnifications for interior work are seldom advisable. There is also another factor which tends to make the use of low magnifications the rule in architectural work, the position of the camera is comparatively near to the object to be photographed, when great magnifying power is not so necessary.

When taking photographs of architectural details on the outside of buildings, the question of exposure is less important and high magnifications can be used.

The greater the power in use the more are the errors of the positive increased.

Effect of the atmosphere.

In England the proverbial dampness of the climate is a drawback to the use of the telephoto lens, but it is a well understood fact that the Isochromatic screen greatly aids the power of penetration of the lens. It reduces the deleterious effect of the mist,[*] and when the light is strong it should always be used.

The exposure increases in the usual ratio, so that a screen lengthening the exposure necessary with the positive alone, 4 times, will increase the exposure necessary with the telephoto system by the same amount.

Beck-Harris spectrum filter.

A screen has been introduced by Messrs. R. & J. Beck, Limited, specially for use in this connection ; it is known as the Beck-Harris spectrum filter. It is not of the usual commercial kind but is made of a material that cuts off the blue portion of the spectrum; it will render many a bad day a good one for telephotography. All the telephoto examples illustrating this volume, with the exception of that of the "deer," were taken with the aid of this filter.

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[*] Mist reflects a very large percentage of ultra-violet rays, and a Beck-Harris screen is so computed, that this band is entirely removed from the spectrum without interfering with the intensity of the remainder.

Tremor of the atmosphere.

When photographing by the sea the tremor often present in the air, may prevent a successul photograph, and work should not be attempted with a high magnifying power unless the air is still.*

For those who wish for a simpler, yet complete form of Telephoto Lens—the "Beck (Simple) Telephoto Objective" is recommended; for full particulars, see the end of the book.

APPENDIX TO TELEPHOTOGRAPHY.

(1) CAMERA EXTENSION.

It has been only possible in the tables on the pages at the end of this book to give the camera extensions, etc., for the Beck-Steinheil Orthostigmats. As, however, the telephoto attachment which has been described is essentially one that can be fitted to any type of lens, it has been thought advisable to give some means whereby the photographer can test, what magnifications he may expect when his lens is combined with either a high, standard, or low power attachment, together with the camera extension that is necessary.

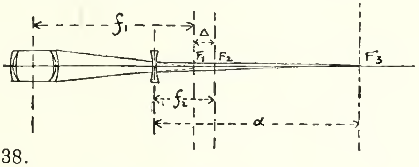

Figure 138.

In figure 138.

Let f_1 be the focus of the positive lens.
,, f_2 be the focus of the negative lens.
,, $\propto$ be the distance of the final image from the negative lens.
,, E be the enlargement or the magnification.
,, $\triangle$ be the focal points of the positive and negative lenses.
,, f_3 be the focus of the final image.

From the above data and the application of well-known optical formulæ the following results can be readily obtained.

$$\text{I.}\quad \triangle = \frac{f^2}{E}$$

$$\text{II.}\quad \propto = E\,(E-1)\;\triangle$$

---

* For lenses suitable for use with telephoto attachments and for the telephoto attachments themselves, see end of book.

Applying these two equations to concrete examples—if a lens of 6 inch focus is combined with a negative lens of 3 inch focus and a magnification of 3 is required it is found that

$$\text{I.} \quad \Delta = 1.$$

$$\text{II.} \quad \infty = 6''.$$

So that if a photographic lens such as the one indicated above belongs to a photographer and he wishes to know what camera extension will be required for a given magnification, he can readily find it. In this case it will be 6 inches from the negative element.

In the smaller size telephoto attachments the mount is so arranged that the negative element is flush with the front, and these figures can be relied on. In the larger sizes the distance which the negative element protrudes into the camera must be added; this will run to 3 inches in a whole plate. It will be seen from the foregoing that the focus of the positive does not affect the camera extension for a given magnification, provided the same focus negative lens is considered in each case. Thus the extension of 6 inches arrived at would be correct for a positive of 10 inch focal length. The only difference being, of course, that the positive would produce a larger image in the first case, of an object at a distance, so that when magnified three times the resultant image would be larger than that of the 6 inch lens magnified the same amount.

(2) AREA OF CIRCLE OF ILLUMINATION.

The focus of the positive does, however, affect the diameter of the field illuminated at any given magnification, this in turn governs the size of plate, which a particular combination of positive and negative will illuminate. This matter is of some importance to anyone desirous of knowing what a proposed combination will do, and a means of finding the circle of illumination is appended, whether the element chosen be high, standard, or low power.* It may be necessary to find out whether a magnifying power of 3 will cover a given plate.

Let a be the diameter of the negative element.†
,, b be the diameter of the effective aperture of the positive lens.
,, f_1 be the focus of the positive, and f_2 of the negative.
,, $\propto$ be the distance of the negative lens from the plate.

Then the diameter of the field will be—

$$= \frac{\propto}{f_2} \times \frac{a f_1 + b f_2}{f_1 - f_2}$$

Thus if—

$a = 1$ inch.
$b = 1$ inch.
$f_1 = 6$ inches.
$f_2 = 3{\cdot}3$ inches.
$\propto = 10$ inches (see previous formulæ).

$$= \frac{10}{3{\cdot}3} \times \frac{6 + 3{\cdot}3}{2{\cdot}7} = 10 \text{ inches approx.}$$

---

*See Dallmeyer (telephotography, page 86).

†The diameters of the various negative elements supplied by Messrs. R. & J. Beck, Ltd., are given in their catalogue at the end of the book; these are suitable for fitting to any positive.

SUPPLEMENTARY LENSES (MAGNIFIERS).

Magnifiers: their introduction.

The addition of a low-power or long focus lens to a photographic objective was described many years ago in photographic publications, more especially in connection with the correction of distortion in a single view lens, but the idea that it could be made use of in a general way was not realized until about 1892, when Messrs. R. & J. Beck, Limited, issued the "Frena magnifiers."

There was a valid reason for the use of the word "magnifier" to designate these additional or supplementary lenses. They were introduced to overcome the difficulty experienced with all fixed focus cameras, viz., of obtaining sharply defined pictures of near objects. By their aid it was possible to procure a larger or magnified picture of objects of small size. A photograph, say of a coin taken with an ordinary fixed focus camera, would be scarcely larger than a pin's head owing to the fact, that to obtain a sharp picture, the object would have to be placed at least ten feet away from the camera.

Frena magnifiers.

By the use of the Frena magnifiers it might be sharply focussed at a distance as near as a foot. Magnifiers are, in fact, low-power lenses so constructed that they do not, to any extent, damage the qualities of the photographic lens, and are placed as close as possible in front to alter the focus, and thus change the range of definition. The effect of combining a positive lens with another is to shorten the combined focus in a definite ratio. If the added lens be a negative lens the effect is to lengthen the focus.

Rule for finding focus of a combined lens and magnifier.

The method of estimating the focus of the final combination is as follows—Multiply the foci of the two lenses together, then add the two foci together and deduct the distance apart of the two lenses, and divide the latter amount into the former.

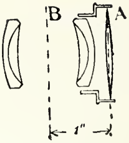

Figure 139.

Effect of the supplementary lens.

Take an actual example, in figure 139 B is a rectilinear lens of say 6 inch focus, and A is a "magnifier" in front of it slipped over the hood or in some other manner brought close to the lens—the separation between A and B is, however, an inch. Apply the rule the focus of A being 20 inches, $6 \times 20 = 120$, and this is to be divided by $6 + 20 - 1 = 25$ and divide 120 by 25, and the result is 4 4-5 as against 6 inches. If the additional lens had been a negative* the result would have been different, $6 \times -20 = -120$, and this divided $6 - 20 - 1 = -15$, and minus 15 into minus $120 = 8$ inches, the focus of the lens would now be 8 inches.

Reason for their use.

A quarter-plate hand camera, fitted with a 5½ inch lens, would render all objects from 30 feet to the horizon sharply with an aperture of f/11—if, however, it was called upon to depict sharply an object at 3 feet from the camera (see plate XLII.), it could not do so unless the distance from the lens to the plate was increased from 5½ to nearly 6 inches by a focussing motion:—in a fixed focus camera this is impossible, and the only alternative, to produce a sharp picture, is to use a shorter focus lens. This is what happens when a magnifier is added, it shortens the original focus to such an extent that it is only near objects that are rendered sharply, distant ones becoming blurred and indistinct because they come to a focus short of the position of the plate.

If the reader possesses a fixed focus camera and no magnifiers, the following is a rough and ready method of discovering of what focus they should be to give objects at a given distance in focus.

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* It is totally incorrect to call a negative supplementary lens, a telephoto attachment; its action is different and the properties also.

Choosing a magnifier.

If fitted close in front of the lens they should be of a focal length equal to the distance which the object to be photographed is from the camera. Thus, for an object 11 inches away, an 11-inch magnifier as thin as possible must be added; for 9 feet a lens with a focus of 108 inches is necessary.

Effect of the magnifier in the lens.

The largest demand for supplementary lenses is to photograph objects between 3 and 30 feet from the camera, these have only slight curvature and can be made thin. The optical properties of the lens they are combined with will not be much impaired if the surfaces of the supplementary lenses are optically worked. The quality of the ordinary spectacle lens is of too low a grade; incorrect centring of the magnifiers will not aid definition, and it is always well to get these supplementary lenses adjusted to the positive by an optician of standing. If, on the other hand, magnifiers of much higher power are used for focussing objects close to the camera, it is essential that they be carefully adjusted to the lens by a competent craftsman, as the slightest alteration of the separation of the two lenses or of their centring will materially affect the quality of the definition and the position of the focal plane. They should also be made of the meniscus form.

Dangers to be guarded against in selecting magnifiers.

Negative supplementary lenses.

The employment of a negative in place of the positive supplementary lens is only applicable to focussing cameras that are capable of considerable extension. In a fixed focus box instrument they cannot be used, as instead of shortening the focus and thus bringing the field of sharp focus nearer to the camera, they increase it to a point beyond the position of the plate.

It must not be supposed that these negative lenses placed in front of the photographic positive are telephoto attachments, for their action is entirely different and merely slightly alters the focus without reducing the camera extension required.

Engraving depth of focus.

It is important to know the range of distances which are in focus with a given magnifier, particularly if the camera is not possessed of a ground glass. It is often the case that one distance only is engraved ; this is of little use, for it is quite impossible to gauge the distances as accurately as this would necessitate. The "Frena" system of magnifiers is the better, as the depth of focus is engraved on each supplementary lens for a given aperture of the lens ; there is no difficulty then, in choosing the additional lens to give any required result. It is comparatively easy to judge if an object is not nearer than 9 feet or further away than 30 feet, but it is difficult to say when it is exactly 12 feet away.

Stopping down.

However carefully the curves of supplementary lenses are computed, there is a tendency to disturb the corrections of the one to which they are added, and this, combined with the fact that it shortens its focus, makes it advisable to stop down when using high-power magnifiers.

Aperture of the lens when using magnifiers.

A great advantage attached to the use of these lenses as a means of focussing is that the effective aperture of the whole remains unaltered, that is, f/11 is always f/11, whether the object being photographed is life-size or very small. In a focussing camera this would not be so ; if the object was at a great distance f/11 would be f/11, but bring it so near that it is life-size on the ground glass and f/11 is f/22, though the engraving on the diaphragm remains the same. Few people take this into account in hand camera work, and consequently under-expose for near objects. A box camera with magnifiers for focussing can always be used accurately with an exposure meter.

A table is attached which may be interesting to box camera workers who are anxious to know, and increase the scope of their instrument to copy curios, ornaments, etc.

Table of special magnifiers for different distances.

FOCUS OF FIXED LENS.*

Size of Picture.	4¼ in.			5½ in.			6 in.			6½ in.		
	Distance of Object.	Focus of Magnifiers.	Depth of Focus f/11.	Distance of Object.	Focus of Magnifiers.	Depth of Focus f/11.	Distance of Object.	Focus of Magnifiers.	Depth of Focus f/11.	Distance of Object.	Focus of Magnifiers.	Depth of Focus f/11.
Full Size.	In.	In.	in.	In.	In.	in.	In.	In.	in.	In.	In.	in.
1/20	84	84	46	108	110	46	120	120	46	132	130	46
1/15	60	60	24	84	82	24	90	90	24	96	97	24
1/10	42	42	10	54	55	10	60	60	10	66	65	10
1/8	34	34	6	44	40	6	48	48	6	52	52	6
1/5	21	21¼	3½	27½	27½	3½	30	30	3½	32½	32½	3½
1/4	17	17	2	22	22	2	24	24	2	26	26	2
1/3	12¾	12¾	1¼	16½	16½	1¼	18	18	1¼	19½	19½	1¼
1/2	8½	8½	¾	11	11	¾	12	12	¾	13	13	¾
2/3	6¼	6¼	½	8¼	8¼	½	9	9	½	9¾	9¾	½
4/5	5	5	¼	6¾	6¾	¼	7½	7½	¼	8	8⅓	¼
Full Size	4¼	4¼	0	5½	5½	0	6	6	0	6½	6½	0

Note what is the focus of the lens in the camera, say it is 5½ inches approximately, and then determine what size of picture is required and examine the first column. The distance at which the object must be placed and also what focus magnifier must be used will appear in the two columns underneath the focus of the lens (5½). For the rapid and accurate copying of maps, pictures, etc., this is the best method. A magazine camera placed at the required distance allows of a number of pictures being taken consecutively without any fresh adjustment.

KINEMATOGRAPH LENSES.

Kinematograph lenses.

The process of making a continuous series of pictures or instantaneous photographs for exhibition is at present too complicated and

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* These figures do not pretend to be absolutely accurate, they merely act as a guide.

A Kinematograph lens.

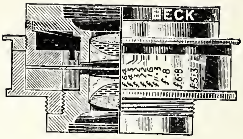


Figure 140.

costly to attract the amateur, but a book on lenses is not complete without some reference to the special lenses required. In making a kinematograph negative a continuous series of from 15 to 30 instantaneous photographs must be taken every second, and each individual photograph will require an exposure of 1-30th to 1-100th of a second. The shorter the exposure the better, provided there is sufficient light to produce a well-exposed negative. The matter of chief importance in considering the lens that is the most suitable for this work is the question of brilliancy of definition. The cost and difficulty of manipulating a large number of large sized negatives in a continuous strip necessitates the originals being very small; and for exhibition on the lantern screen they require to be highly magnified, consequently brilliancy and perfection of detail stand as of the first importance. It is true that a slight lack of sharpness caused by movement of the object during the exposure does not seriously injure the effect—because a series of continuous photographs of a moving subject means, that first one part and then another is blurred, and the general effect is true to nature—but the stationary surroundings repeated in each successive picture must be sharp, and any indistinctness at the corners will become unpleasantly prominent with the high magnification that is necessary.

Object of a kinematograph.

Rapidity in the lens (figure 140) is also a matter of some importance, f/6 or thereabouts being sufficient for most purposes, and at times f/8 or even f/11 can be used. The focus will be short so that the attendant defect of great rapidity, namely, lack of depth of definition, is not of importance. The usual lens that is used has a focus varying from 1½ inches to 4 inches according to the size of the picture that is required, giving perfect definition over the whole of the field. It has been the custom to supply a lens of the Petzval form for this work, but an Orthostigmat (figure 140) (anastigmat) is much preferable, the illumination is better and the field flatter, and the marginal definition is greatly improved. The lens that has been employed for taking the photograph is frequently used for its projection on to the screen; this is a mistake, a lens with the largest possible aperture, at least f/4, and better f/3 of the Petzval type should be used for projection, unless the lens is of more than 4 inch focus, in which case it is not of so much consequence.

Rapidity required.

Rapidity for projection.

It is by no means a rule or a necessity, that the lens used for projection should be of the same focus as that with which the picture was taken; a much longer focus lens is preferable on account of the increased distance of the screen from the lantern, and also, as will be pointed out under a following heading, it is the actual size of the lantern lens and not its focal aperture that is the factor which determines the amount of light that will reach the screen.

LENSES FOR STEREOSCOPIC WORK.

Stereoscopic lenses.

The reason why objects in nature appear solid, why they have depth as well as height and breadth, and the means by which their distances and relative positions are judged, is due to the fact that the two images formed on the retinas of the two eyes are not the same. The left eye sees more of the left side of an object, and the right more of the right side, and although we do not possess Sam Weller's power of penetration, each eye sees slightly round the corner, producing in the brain, the effect of solidity, by the combination of the two pictures. The nearer the object is, the more marked will be the effect, and it is by this means that the distance of an object can be estimated.

Experiment in stereoscopic vision.

This can be readily understood by an experiment. If a card with a bright blue on one side and a red on the other be placed with its edge against the top of the nose, and first one eye be closed and then the other, it will be noticed that one side of the card is seen with one eye and the other side with the other, while when both eyes are open a confused purple image of the two colours is obtained. As the card is moved away from the face the two colours are still visible to the different eyes, the effect decreases as it is further off, until at a considerable distance, one eye sees a line bordered with a fine blue edge, and the other a line with a red edge.

Method of obtaining a stereoscopic picture.

In order to produce stereoscopic pictures, two distinct photographs must be made of the same scene, one to be viewed by the right eye, and one to be viewed by the left. These two pictures must be different, one being taken from a point slightly to one side of the other. A casual examination of the subject will show that the reason why each eye sees a slightly different picture is through their being at a slight distance apart; the further apart they are the more marked the roundness of the object. Mr. Thomas De La Rue made some curious photographs of the moon, which, when combined in the stereoscope, show it as if it

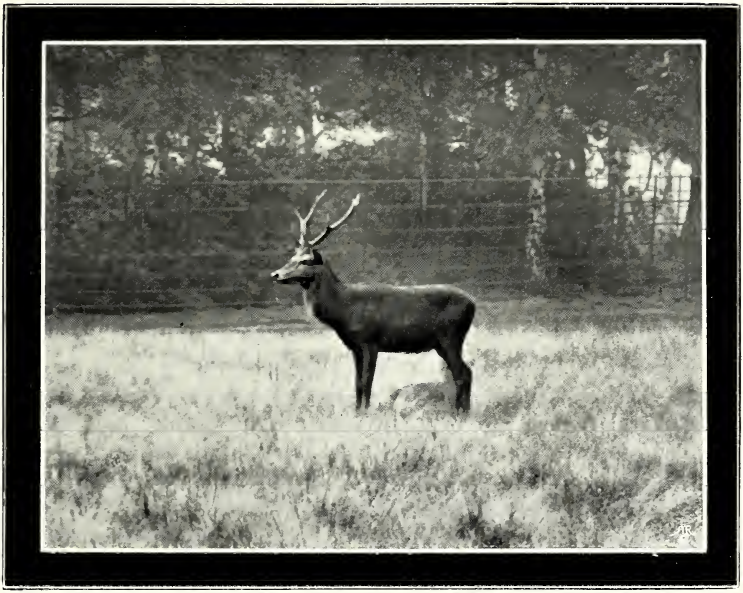
The moon.

were an apple close to the observer. It represents exactly how it would appear to a giant whose eyes were 20,000 miles apart. These stereoscopic photographs were obtained by taking advantage of the swinging motion or libration of the moon, and choosing suitable times of the year for procuring the photographs which were identical in all other respects,

See page 242.

PLATE XLIV.

DEER IN RICHMOND PARK.

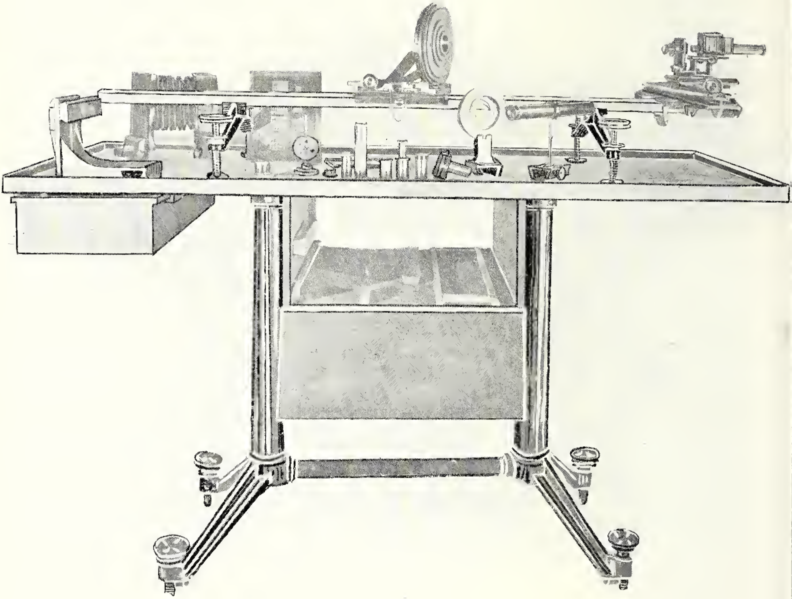


Negative by *W. H. Wilkins.*

A telephotograph of a Buck in Richmond Park. Lens used, a No. 5 Beck-Steinheil Orthostigmat, f/6·3, and a low power attachment. Magnification 8 times.

See page 271.

PLATE XLV.



Lens-testing Bench, manufactured by R. & J. Beck, Ltd., 68, Cornhill, London.

PHOTOGRAPHIC LENSES

except, that one showed a little more round the edge than the other.

Factors governing the choice of lenses for stereoscopic work.

The factors that govern the selection of lenses for stereoscopic work are the same as those for the branches already discussed, but there are one or two considerations which apply more particularly to this work. Most stereoscopic pictures are produced in a double camera specially constructed for the purpose, which has two lenses side by side about three inches apart. The two lenses must give identical images as to size and brilliancy, as these two images are to be combined into one in the stereoscope. It is not sufficient that the back foci of the lenses be the same; that is, that the distance of the plate from the back surface of the lens is the same, for it by no means follows that their actual equivalent foci will be equal. The size of the image is governed by the equivalent focus, and if the equivalent foci be not the same, the images will not be equal. In stereoscopic work it is convenient to produce both images on the same plate, and upon the same sensitive salts of silver, consequently two prints are produced of the same value as to depth and tone, the exposure for both pictures must be identical. It is easy to produce a shutter that will give the same exposure to both portions of the plate, but it is not so easy to produce two lenses and two shutters that will allow of the passing of the same amount of light to their respective pictures on the same plate. The most important consideration in this connection is the actual aperture of the diaphragm—though the construction of the lens itself is of sufficient importance as to preclude the use of two different types of lenses. The size of the picture employed for use in the stereoscopic camera is usually double $\frac{1}{4}$-plate size and is restricted by several causes; hence the choice of foci is also limited.

Size of picture.

Influence of focus upon stereoscopic effect.

The choice of a long focus lens gives a better and more truthful perspective rendering, but it reduces the effect of solidity and depth in the finished print, and objects do not stand out so prominently from each other. A long focus lens includes little foreground, and therefore the prominent objects must be at a considerable distance from the camera. If marked stereoscopic effect is desired a short focus lens should be chosen, and to get over the difficulty of poor stereoscopic effect attendant upon the use of long focus lenses, the separation of the latter must be increased.

Effect of separation on stereoscopic vision.

In the normal man the eyes are situated about 2½ inches apart, and if this distance could be increased, to say 3 ft., it would be possible to tell whether a tree 3000 yards away was nearer or further off than one situated to the side of it at either 2950 or 3050 yards, in other words the stereoscopic effect would be much increased.

In the same way the separation of the two lenses in use is usually some 3 inches from centre to centre; if this be increased to say 4 inches, the stereoscopic effect will be correspondingly heightened, and it will be possible to get a sufficient effect of solidity with lenses of a longer focus. Lenses from 3 to 5 inches focus should be placed about 3 inches apart, and longer focus lenses 3 to 4 inches according to circumstances.

The stereoscopic picture when finished is familiar to all. There are two almost identical prints which correspond with the two separate images produced upon the retinas of the two eyes, and it follows that to produce the same effect upon the brain, the left eye must view one picture and the right eye the other. The method followed to obtain this end is as follows: Two positive lenses are mounted in a holder so far apart that the eyes perforce look through the edges, and the picture is placed at a distance of some 8 or 9 inches from them, while a division runs from between the eyepieces to divide the pictures. The eyepiece lenses are generally made prismatic so that there is no difficulty in combining the two images as one.

The projection of stereoscopic pictures on the screen.

To project stereoscopic pictures on a lantern screen has often been attempted, and it would be difficult to imagine a more effective exhibition than this, if it could be done, but a momentary reflection will show the difficulties in the way.

By polarized light.

To procure a stereoscopic effect, each eye must see a different picture. By the stereoscopic camera these two pictures can be produced—so far so good; but if two transparencies are thrown on to the same screen one on top of the other so as to coincide, no stereoscopic effect will result, it is merely as if a single plane view of the piece of scenery were exhibited, because both eyes now see both pictures, which, not being identical, simply serve to confuse each other. In order to solve this difficulty, several methods have been attempted. One is as follows: two lanterns are arranged side by side as suggested, and in each, either in front or behind the objective, is placed a large polarizer, the one with the prism vertical and the other with the prism horizontal. Each observer is provided with a pair of analyzing prisms in a spectacle frame which are likewise the one vertical and the other horizontal. It is known to most that if light which has been passed through a polarizing prism be viewed through an analyzing one at right angles, it is extinguished or blocked out. This is the principle that is applied in the case under consideration. The polarizer in the left-hand lantern is vertical, and the analyzer in the left eye is likewise vertical, while the right-hand polarizer is horizontal as also is the right-hand analyzer.

It follows that none of the light emitted from the left lantern can enter the right eye because the polarizer and analyzer are crossed, and vice versa, so that the left eye can only see the picture on the screen produced by the left lantern and the right that thrown by the right lantern; hence the same effect is produced as in a hand stereoscope. Clearly this method is not possible under ordinary circumstances, as it necessitates two analyzers for every one in the room, and is therefore much too costly and elaborate for practical use.

Revolving wheel.

Another method that has been attempted, is to have a revolving ray wheel in front of the two lanterns so that first one and then the other is cut off, and a similar contrivance in front of each of the spectators, synchronized with that on the lantern, so that each eye shall receive only the image intended for it. This again is impracticable. A third method is to project two pictures on to the screen side by side and to use a prismatic apparatus similar to an ordinary hand stereoscope. This again is not practicable as to view the pictures the audience must be in the centre of the room. Yet another modification is one in which two differently coloured pictures are thrown upon the screen and the spectators use differently coloured spectacles, but this presents similar difficulties and the exact arrangement of suitably coloured images prevents any general adoption of the plan.

LANTERN CONDENSERS AND OBJECTIVES.

Lantern condensers.

The optical portion of the lantern, whether for exhibition purposes or bromide work consists of the condenser and the objective.

The purpose of the condenser is to gather as many rays of light as possible coming from the illuminant, and to bend them so as to pass through the slide or negative on the way towards the objective.

Function of the condenser.

If no condenser were used the picture on the screen would only be the size of the portion that is actually in front of the light itself. In figure 141, L is the illuminant, S the slide, and O the objective or lens. When no condenser is used the light collected by the objective or projecting lens after having passed through the slide is contained within the two lines indicated. If a condenser C is placed in the path of the rays proceeding from L, those rays of light contained within the dotted lines are received by the objective and passed on to the screen. They include rays coming from every portion of the slide, so that the slide will be completely projected on to the screen and not only one small portion.

Intensity of illumination.

The intensity of the illumination is dependent upon the amount of light the condenser first collects and then converges into the objective; the usual arrangement is illustrated in figure 142 (a). A pair of plano convex lenses having a combined focus of about 2½ inches will receive an angle of about 80°. The addition of a third lens of a meniscus form between the light and the condenser, to catch a rather larger angle of light, by refracting the rays that would pass beyond the original condenser, will increase the angle to 90° (figure 142b), for the additional lens of necessity shortens the focus of the system and thus allows the light to be placed nearer to the condenser. Other and still more complicated forms of condensers have been devised to throw the light more

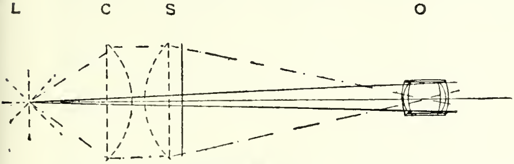


Figure 141.

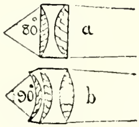


Figure 142.

accurately towards and into the objective—the forms that are illustrated being but partially corrected for spherical aberration. The expense of the more complicated forms is so great, that their use has not become by any means general.

Function of the condenser.

The function of the condenser is not the same as that of a photographic lens, it has not to produce an image of an object, its function being to collect as much light as possible from the source of illumination and to distribute it evenly over the negative or slide, and then to converge it—the whole if possible—into the objective or lens. If the place of the condenser were taken by a ground-glass plate this would, by its scattering power, distribute the light evenly over the slide, but would not collect additional light from the illuminant, and so far from converging it down to and into the lantern objective, it would scatter the light in all directions. To illuminate the whole slide the light would have to be as large as the slide itself.

Conjugate foci of condensers.

A condenser is a lens and has, therefore, two conjugate foci which play an important part in enlarging work. Suppose, for instance, that the lantern is arranged as in figure 143 with the light at L (F is the first conjugate point), the second conjugate point is at F′; the objective must be placed at this point to receive the light converging through the slide towards it. The condenser must be so constructed and adjusted that the conjugate focal point F′ falls approximately in the centre of the projecting lens, when this is focussed to give a sharp image on the screen in use. If

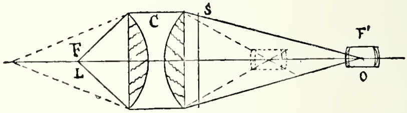


Figure 143.

Effect of conjugate foci in the illumination of the screen.

by bad adjustment of the light the point F′ is in front of the lens, because the latter is in the position indicated by the dotted lines, a portion only of the light will pass through the lantern lens, and the rest will be wasted. Again, if the objective be of short focus, and in consequence be in the position indicated by the dotted lines, the condenser will have to be moved backwards till the second conjugate focal point lies in the centre of the lens.

Effect of imperfectly corrected condensers.

Effect of the size of the objective.

It is essential for good illumination that the light, its conjugate point and the objective be in one and the same straight line, or the illumination will be uneven, a dark crescent appearing on the screen. The diagrams just given assume that the condenser is so well corrected that all the light emanating from L is condensed completely to a perfect point at F′. This is not strictly true, the commercial lantern condenser is but partially corrected, and if the light comes from a perfect point it will not be condensed to a corresponding one, but to a disc an inch or so in diameter. When the illuminant is, for instance, limelight, the area from which the light comes is not a point, but is at least the size of a sixpence, so that the circle to which the light is condensed will be larger still, as indicated in figure 144. An objective to receive all this light must, therefore, be of a large size, which would not be necessary if the corrections of the condenser were better. Hence a portrait lens with a diameter of some $1\frac{3}{4}$ to 3 inches is used, not because its optical properties are such as to warrant its choice,

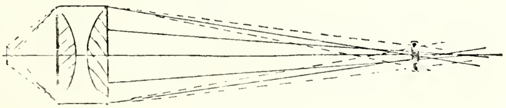


Figure 144.

but because of its size; in fact, portrait lenses have often such curved fields that they do not cover a lantern slide ($3\frac{1}{4} \times 3\frac{1}{4}$) sufficiently well, to throw a sharp picture on the screen.

The biplanat as a projection lens.

This question of size raises an interesting point—provided the lens has an aperture of about 2 inches, extra rapidity is of no advantage with any reasonably good condenser. Thus, although a 6-inch lens requires an aperture of f/3, a 12-inch lens at f/6 would allow the same amount of light to pass. If one is content to use a long focus lens, say a 9-inch, a lens of the type of the Biplanat can be advantageously used in place of the usual Petzval form, as, for the reason just given, a Biplanat is large enough to receive all the light that is required.

PHOTOGRAPHIC LENSES

BRIEF SUMMARY OF THE CHIEF POINTS IN SECTION VII.

(1) A telephoto lens consists of an ordinary photographic lens combined with a telephoto attachment or special negative lens.

(2) It is a long focus lens, requiring only a short camera extension.

(3) It possesses an adjustment for altering the focus at will, and consequently forms a series of different long focus lenses.

(4) It gives pictures of an object on a larger scale than an ordinary lens, and the amount of magnification is variable.

(5) The magnification is directly dependent on the focus, and is ascertained by reference to an engraved scale on the mounting.

(6) The angle of view included in the total field for a given telephoto lens is always constant and is about 12°.

(7) The equality of illumination is slightly improved by stopping down the positive.

(8) The depth of focus is slight, but as in an ordinary lens, is increased by stopping down the positive.

(9) The requisite exposure is calculated by multiplying that required for the positive alone, by the square of the magnification.

(10) The aperture or rapidity of a telephoto lens is ascertained by multiplying the aperture of the positive by the magnification.

(11) The telephoto lens should not be used at an aperture less than f/72, because of the loss of definition, by diffraction.

(12) The positive must have rapidity and equality of illumination giving no distortion, and be free from astigmatism and spherical aberration, as the negative element increases all errors present in the positive in proportion to the magnification used.

(13) Use the lowest magnification that gives the required result.

(14) The required camera extension can be found by the formulæ given in Appendix I. (Telephotography).

(15) The diameter of the circle of illumination with different negative elements can be found in Appendix II. (Telephotography).

(16) Magnifiers alter the focus of the lens they are added to, and so allow objects at nearer distances than can be taken with the lens alone, to be sharply depicted, even in a fixed focus camera.

(17) To photograph objects at a distance of 20 feet sharp, a 20-ft. focus magnifier must be added.

(18) If the supplementary lens is a negative, it increases the focus of the original lens.

(19) Magnifiers are optical accessories, and should be treated as such.

(20) Magnifiers, when used for focussing on box model fixed focus cameras, do not alter the actual aperture of the lens.

(21) A table of distances is given, at which objects must be placed to get results of a given size.

(22) Kinematograph lenses are of short focus, and must give the very finest definition at full aperture.

(23) A pair of stereoscopic lenses must have identically the same equivalent focus.

(24) The distance apart of the lenses affects the stereoscopic effect, the further apart the greater the apparent solidity.

(25) Several methods of projecting stereoscopic pictures on the screen are given, none of them are practical.

(26) Projection requires the employment of two optical systems, the one a collecting and converging system, the condenser.

(27) The other, the projecting system, the lantern objective.

(28) The more light the condenser collects the more brilliant the image on the screen.

(29) Any mark on the condenser will appear on the screen.

(30) The light must be brought to a point by the condenser, and this point must be in the centre of the lantern lens.

(31) This point, in a commercial condenser, is usually about two inches across, because the condenser is but partially corrected.

(32) The objective or projection lens must be able to collect the whole of this light if the illumination is to be good.

(33) The rapidity of the objective is of no importance, it being the size or diameter that matters; thus, a 16-inch lens at f/8 will pass as much light as an 8-inch lens at f/4, and therefore be as rapid for this work.

APPENDIX. I.

A SIMPLE EXPLANATION OF THE PROPERTIES OF THE "EQUIVALENT PLANES."*

This term has been used in several places in this book, and as the explanation is not usually met with in popular treatises, its discussion will be attempted.

These planes are known under several names—"Gauss planes," after their discoverer, principal planes and nodal planes. Photographers know them chiefly from the fact that they occupy the position from which the true equivalent focus is measured.

Their existence pre-supposes the assumption that a lens is so well corrected that all the rays of light are influenced by the lens in the same manner. That is to say, the light passing through the margins of the lens is refracted in the same manner as that which passes through the centre; that oblique bundles of light are accurately corrected for the various errors, etc.

Strictly speaking, the properties possessed by these planes are only accurate for the rays passing through the exact centre of an uncorrected lens, but as all good photographic lenses are approximately free from aberration; the properties of these planes can apply to these good lenses.

By means of the equivalent planes, a well-corrected compound lens, no matter of how many individual lenses it may be composed, can be treated of in the same simple manner as an infinitely thin lens. The problems that the photographer is likely to meet can be simply solved by their use—such as the relative image sizes produced by lenses of different focus, the combination of one lens with another as in the telephoto attachment, or the addition of supplementary lenses as exemplified by the Frena system of magnifiers; and although it is beyond the scope of this book to thoroughly elaborate their mathematical use, an explanation of their properties may render easy the better understanding of lens problems.

PROPERTIES OF A THIN LENS.

Let figure 145 be a thin lens, so thin that its surfaces may be considered to coincide with the line AB. It is also supposed to be free from all aberration. Let FF′ be its foci or the points to which a bundle of parallel light is brought to a point on the two different sides of the lens. The actual positions of these focal points may be calculated from the curves of the lens and the refractive index of the glass from the following equation.

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* The term "Equivalent Planes" is used to denote the nodal and principal planes when they are superimposed and form a combined pair, which is always the case when the outer medium on both sides of the lens system is air.

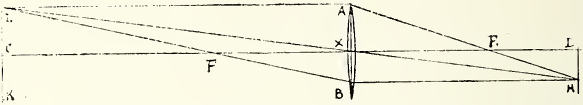

Figure 145.

$$\frac{1}{\phi} = (\mu-1) \left[\frac{1}{r} - \frac{1}{r'}\right]$$

Where ϕ = focus of the lens.
,, μ = refractive index of the glass.
,, r = first radius of curvature.*
,, r' = second radius of curvature.*

The focus may be taken experimentally by measuring the distance of the focal plane or point from the lens, when considering a distant object, such as the sun.

Conjugate Foci.—If the light from a point C is focussed to a point D, the points C and D are called the conjugate foci, and if the lens produces a picture of an object EK in the plane GH, the planes EK and GH (figure 145) are called the "conjugate planes."

To find the position of these conjugate points or planes is simple with a lens whose focus is known. The graphic method is as follows.

Let an object, say EK, be selected in the position shown in the figure. [The following method, however, will apply equally well to an object placed in any position] : From the point E on the object EK draw a straight line through the focus F, this ray will emerge as BH, because all the rays of light that pass through the point F will emerge from the lens parallel to the axis. Now from E draw a line parallel to the axis of the lens, and this will emerge from the lens to the second focus F′, and pass through this point to H, consequently H will be the position where rays from E will be focussed to a point, and H will be the conjugate point to E.

Another property of a thin lens might have been used to find this point—a ray of light which passes through the centre of a thin lens will not be bent during the process and, therefore, if only one of the previous rays had been drawn, and a straight line EX had been produced through the centre of the lens, the point H could have been found.

By this means the distance apart, of any object and its image, formed by a thin lens of a given focus can be found, and also the relative size of the image and object.

By simple geometry the distance of the two conjugate foci and the size of their images can be deduced from this diagram.

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* If the centre of curvature is to the left of the lens, the radius of curvature has a minus (—) sign, if to the right a plus (+) sign.

The formulæ are as follows, their proof from figure 145 will be readily appreciated by those who are familiar with mathematical methods.

$$(1)\quad \frac{1}{x} - \frac{1}{x} = \frac{1}{\phi}$$

$$(2)\quad \frac{y}{y'} = \frac{x}{x'} \qquad (3)\quad \frac{y}{y'} = 1 + \frac{x}{\phi} = 1 - \frac{x'}{\phi}$$

Where ϕ = the focus of the lens.
,, x = the distance (CX) of the object from the lens.*
,, x' = the distance (XD) of its image from the lens.*
,, y = the half size of the object (CE).†
,, y' = the half size of its image (DH).†

When two lenses of known focus are combined the focus of the pair may be obtained as follows.

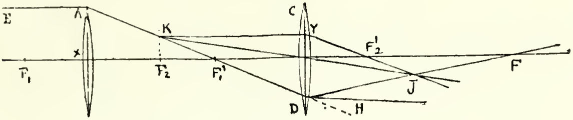

Figure 146.

In figure 146 let AXB and CYD be the two lenses with foci at $F_1 F'_1$ and $F_2 F'_2$ respectively. It is now necessary to know the focus for parallel light through the combined pair. Draw the line EA parallel to the axis, and this will emerge from the lens A through its focus F'_1, in the direction AF'_1, H. From the point K, where this line cuts the focal plane F_2 of the second lens—draw a straight line parallel to the axis (KC), this will emerge from the second lens through its focus at F'_2 and pass as KYJ.

Draw a line (KJ) through the point K and through the centre of the lens CD; this represents a ray of light that passes through without refraction, and where this ray KJ cuts the former ray YJ, namely, at the point J, will be the conjugate focus of the point K, consequently the ray KD will after emergence pass through it. Therefore DJF is the ray that corresponds to an incident parallel ray EA after passing through both lenses, and the point F, where it meets the axis, is the focal point of the combined pair of thin lenses.

The following is the formula which may be deduced from the foregoing diagram :—

$$(4)\qquad = \frac{\phi_1 \phi_2}{\phi_1 + \phi_2 - \Delta}$$

Where ϕ = is the focus of the combined lens.
,, ϕ_1 = is the focus of the first lens.
,, ϕ_2 = is the focus of the second lens.
,, Δ = is the distance between the two lenses.

---

[*] The distances x and x' are considered plus (+) if they are on the right-hand side of the lens; minus (—) if they are upon the left.

[†] The distances y and y' are considered plus (+) if they are above the axis; minus (—) if they are below the axis.

By the aid of the foregoing formulæ most of the simple problems connected with the size and position of images formed by lenses may be worked out either algebraically or by the drawing board, but with lenses infinitely thin and without aberration, errors are not met with except in theory.

It was, however, discovered by Gauss that by means of a system of what are called the equivalent planes, all these simple formulæ could be applied, without alteration, to lenses, however complicated, provided they are approximately free from aberration. Let figure 147 represent a complicated series of lenses, with focal points at F and F′. It was found by Gauss that there were two planes in certain positions E and E′ which possess peculiar properties.

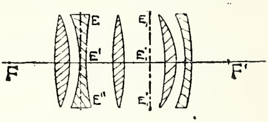

Figure 147.

Suppose an infinitely thin lens with a focus of F′E′ be placed in the plane EE′E″ to receive the light, and that before the light has time to pass through, the lens was rapidly shifted along to the positions $E_{\cdot}E'_{\backslash}E''_{\backslash}$ and that from this position the light emerges from it under the same laws as that for the thin lens, the whole of the properties of the complicated lens system can be explained by this so-called equivalent lens, which is made to be in one equivalent plane to receive the light and to immediately jump to the other to usher it out. The front equivalent plane is, as it were, the front door of the unknown lens system; no notice is taken of what happens inside, but the second equivalent plane or back door is steadily watched to examine the issuing or emergent light.

In this way, the most complicated lens obeys the same simple laws as the thin lens. The nature of the compound lens determines the positions of the planes EE′E″ and $E_{\backslash}E'_{\backslash}E''_{\backslash}$, but their position having once been found, no further account need be taken of the form of the lens itself.

From the definition of these planes it will be evident what are their special properties.

In a thin lens (figure 148) the line to the centre of the lens passes straight through without refraction, but if the lens has to be at E to receive the light, and at E′ to discharge it, the ray will now not pass straight through, but only emerge in a direction parallel.

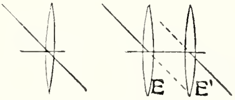

Figure 148.

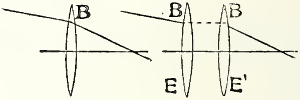

Figure 149.

Therefore, the points where the planes cut the axis have the property that rays of light that enter towards one point, emerge from the other in a parallel direction. In a thin lens (figure 149) a ray of light which falls upon the lens at the point B has its direction altered according to the focal power of the lens, but emerges from the same point B. But if the lens is at E to receive the light and has to jump to E′ to allow the light to emerge, then the ray that arrives at B will emerge from B′, and B and B′ are the same distance from the axis.

Thus any ray of light that enters the lens in a direction towards a point on the first equivalent plane, emerges from the lens as if it came from a point at an equal distance from the axis on the second equivalent plane.

Any corrected lens may therefore be replaced for theoretical purposes, by a so-called equivalent lens, which has the power of jumping from one plane to the other to receive and discharge the light.

Having ascertained the position of the equivalent planes and the equivalent focus of the lens—the actual construction of the glasses can be dismissed entirely,—work will be continued as though the lens consisted of two lines with a single thin lens of the correct focus, jumping from one position to the other.

The formulæ and methods used with a single lens can be adopted without change as follows :—

$$(1)\quad \frac{1}{\chi'} - \frac{1}{\chi} = \frac{1}{\phi} \qquad\qquad (3)\quad \frac{y}{y'} = 1 + \frac{\chi}{\phi} = 1 - \frac{\chi'}{\phi}$$

$$(2)\quad \frac{y}{y'} = \frac{\chi}{\chi'} \qquad\qquad (4)\quad \phi = \frac{\phi_1 \phi_2}{\phi_1 + \phi_2 - \Delta}$$

In this case χ = the distance between the object and the first equivalent plane.

χ' = the distance between the image and the second equivalent plane.

All the other symbols represent the same distances except that the focus ϕ_1 and ϕ_2 are now measured from the equivalent planes.

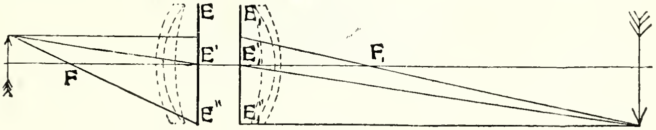

Figure 150.

The geometrical system is also the same except that the planes are used instead of the centre of the lens, as follows :—

The ray, which in the first example passed through the centre now proceeds to the point E′ (figure 150), and emerges from the point E′ parallel to its original direction, the space between EE′ is, as it were, wasted, but in other respects the diagram is the same as 145.

The position of the equivalent planes is dependent upon the construction of the lens—in some cases they are in very curious places,—in a telephoto lens they exist a long way in front of the entire system ; consequently a complete lens is obtained with an equivalent focus of perhaps 100″, while itself may not be more than 10″ from the plate.

The formulæ which give the positions of these Equivalent planes for a combination of two lenses are as follows :—

$$E_1E = \frac{\phi \quad \Delta}{\phi_1 + \phi_2 - \Delta}$$

$$E'_2E = \frac{\phi_2 \quad \Delta}{\phi_1 + \phi_2 - \Delta}$$

Where EE′ are the first and second equivalent planes of the complete system, and E_1 and ϕ_1 are the first equivalent plane and the focus of the first lens, and E'_2 and ϕ_2 the second equivalent plane and the focus of the second lens : Δ is the distance between the second equivalent plane of the first lens and the first equivalent plane of the second lens.

The signs are reckoned as before, if the distance E_1E' works out as a minus quantity the point E will be on the left-hand side of the known point E, or if the sign is plus, on the right.

APPENDIX II.

A DESCRIPTION OF A METHOD OF TESTING PHOTOGRAPHIC LENSES IN CONJUNCTION WITH A LENS TESTING BENCH.

This appendix will describe a method of lens testing, worked out by Messrs. R. & J. Beck, Ltd., for the Photo-mechanical Department of the Manchester Technical School, together with the apparatus which was specially designed for the purpose.

It combines a number of well-known methods, but uses a microscopic examination of the aerial image formed by the lens for all its measurements.

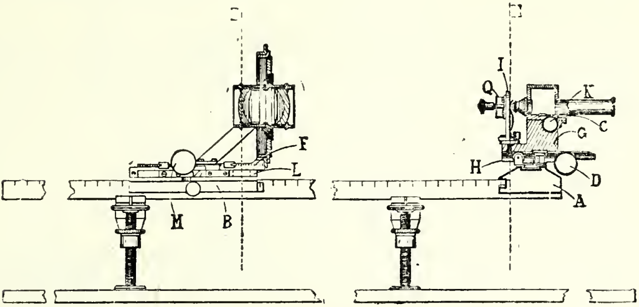

Fig. 151.

A preliminary description of the testing bench will make the actual processes employed more readily understood.

The apparatus, fig. 151 and plate XLV., is carried on a table consisting of a teak wood top, measuring 60 inches × 26 inches, with cupboard and drawer for containing the appliances, and a rigid iron framework running on four castors. At the side of each castor is a screw pillar and clamping lock nut, which, when the table is in position, may be screwed down to lift the table off its castors, so that even upon an uneven floor the table is quite rigid.

Upon the surface of the table are four brass sockets, into which fit the points of four levelling screws, carrying on strong frames a steel dovetailed-shape bar 54 inches long, 1¾ inches wide, and 1⅛ inches thick. Upon this bar slide the various appliances for holding the photographic lens and for examining its image, etc.

1. The Lens Holder (B).—This consists of a series of screwed rings fitting into each other, designed to screw up to one plane, so that any lens screwed into any size ring, will have its shoulder in the same position in reference to the lens holder. These rings or adapters are held in a revolving collar, so that they may be rotated to test the centring of a lens.

The lens holder (B) consists of an upper platform (F) carrying the screwed rings to hold the lenses, which may be moved backwards and forwards by a rack and pinion (M) upon a lower platform (L). This lower platform (L) is affixed by means of a strong circular rotating fitting to the fitting (B), and the whole lens carrier slides upon the bar of the testing bench. Thus the upper two platforms (F) and (L), and the lens holder, can be turned upon a vertical axis (E), and a divided scale of degrees is attached to record the angle of rotation.

The main bar of the testing bench is divided along its length into the metric scale , and the upper platform (F) is provided with an index which reads on a scale on the platform (L), the scale is so arranged, that when the index is set at (O), the surface of the rings into which the lenses screw, is exactly over the centre (E) of the rotating fitting on which the lens holder rotates.

2. The Examining Microscope.—A 24 in. crossbar of aluminium (A) slides along the main bar of the testing bench. This is generally used in such a position that it projects 12 in. on each side of the bar, but it has an extra fitting at each end, so that for examining very large lenses, it may be placed upon the bar so that almost the whole of it overhangs on one side. A light aluminium casting slides in a dovetailed fitting from end to end of the cross bar (A), and its position to the right or left of the centre is recorded on a divided scale with a vernier and fine screw adjustment. At right angles to the crossbar (A) upon the top of this casting, a small table (G) racks backwards and forwards by the milled head (D), and is provided with a scale and vernier. On this table is a centre, to which is attached a frame (I), which carries a small ground glass, micrometer, cross wires or similar appliances. Behind this frame an examining microscope (K) or low power eyepiece is placed, with a rack and pinion focussing adjustment (C), by which it may be accurately focussed upon either the ground glass or cross wires. The frame is so placed that the ground glass or micrometer is accurately in the axis of rotation of the centre (N), and the microscope may be rotated on the same centre. The arrangement is such, that the ground glass may remain stationary, while the microscope is rotated, or that the two may be rotated together. The divided scale on the table is so placed that, when the vernier is set at (O), the distance of the centre of rotation of the ground glass, to the centre of rotation of the lens holder, is read upon the scale of the main bar of the testing bench. The microscope (K) consists of a frame, to one end of which an object glass of any power may be attached by the standard Royal Microscopical Society screw, at the reverse end an eyepiece is placed. Between the object glass and the eyepiece slides a fitting, which carries a triple trough for

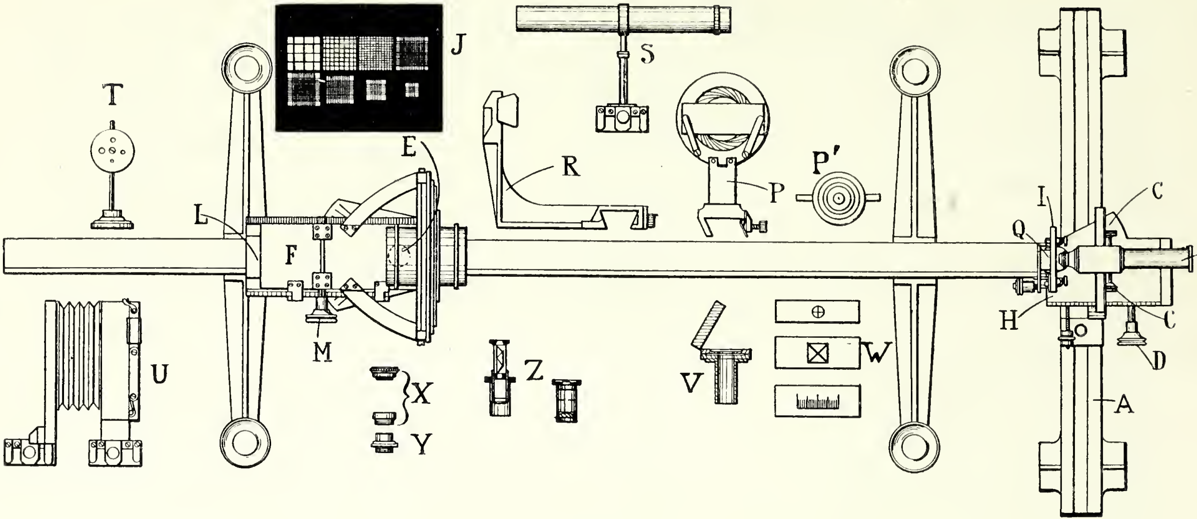

Fig. 152.

Optical Lens Testing Bench.—(F') Lens carrier. (F) Upper platform. (L) Lower platform. (M) Rack and pinion for moving F along L. (E) Centre upon which both F and L swing on cradle which slides along main bar of the bench. (A) Cross bar which slides along main bar, the whole eyepiece apparatus slides laterally along cross bar. (H) Microscope table. (D) Rack and pinion for moving upper table parallel with main bar. (K) Microscope. (C) Rack and pinion for focussing microscope to the ground-glass stage. (I) Ground glass. (Q) Line screen holder. (R) Distortion bracket to receive lens carrier platform (L F) upon main bar at right angles to the normal position. (P) Iris diaphragm and holder for small screens. (P') Set of discs which may be carried on the iris diaphragm (P), to produce anular spaces. (S) Small collimator. (T) Disc with series of apertures to form an artificial star. (J) Test grating. (V) Camera to fit eyepiece of the microscope. (U) Camera to fit on to main bar of the bench. (W) Screens to be used on the stage (I), or the holder (P). (X) Low power eyepiece to replace the microscope (K). (Y) Telescope object glass (Z) Spectroscopic eyepiece.

containing a series of monochromatic solutions. The eyepiece has cross wires, and a special telescopic object glass can be used in place of the microscopic object glass, which turns the microscope into a telescope for reading diameters at a distance. A small camera for one inch plates fits the microscope tube, this takes microscopic photographs of the aerial images produced by a lens.

The Iris Diaphragm (P).—A large iris diaphragm with a divided scale, representing the size of the aperture in m.m., slides on the main bar of the testing bench.

A ¼-plate camera with an extension of 15 inches also slides upon the main bar. It consists of a frame with ground glass and double dark slide, an extending bellows, and a frame to carry a lens.

The Line Screen-holder (Q).—This is fitted to the microscope table so that the effect produced by diffraction upon the image given by the photographic lens may be examined and recorded. A screw adjustment is supplied for moving the screen to or from the ground-glass screen (I).

The Distortion Bracket (R).—This is a bracket which slides upon the main bar carrying the lens holder, can be placed in a plane at right angles, so that the axis (E, fig. 151) is horizontal instead of vertical. The lens should now be swung on its nodal plane, and the distant straight line may be examined by following its image with the moving microscope table along the crossbar (A). Each piece of apparatus which slides along the main bar is provided with a clamping screw and plate. The rotating platform of the holder is provided with a series of holes and a taper bolt, that will lock it in position at every 5 degrees. The rotating centre (N) is provided with a bolt to lock the centres in position of alignment.

LENS TESTING.

Before commencing lens testing proper, certain examinations should be made.

1. Number of external reflecting surfaces.—Their curvature and probable influence on the amount of light which they prevent from entering the camera through reflection should be noted.

2. An Examination of the Lens should be made for veins and striæ.—This may be done by holding the lens between a light and the eye at about the distance of its focus from the latter, so that its whole area appears filled with light. The intensity of the illumination may then be increased or decreased, and by moving the lens about the veins or striæ will show as thread or feather-like appearances.

3. An Examination of the surfaces should be made to determine the perfection of the polishing. It is best done by pointing the lens towards a powerful light, so that direct light does not quite enter the eye—a piece of black velvet should be placed at some distance in front of the lens, to form the background, against which the imperfections in the polishing may be seen.

The optical constants of the lens should now be obtained. They consist of—

(1) Equivalent focus.
(2) Distance of the equivalent planes from the shoulder of the lens screw.

(3) The effective aperture of the various diaphragms.
(4) The diameter of the maximum circle of illumination.
(5) The diameter of equal illumination (theoretical) with the various diaphragms.

The determination of the equivalent focus of the lens.—Three methods will be given.

(I.) The equivalent plane method. Set the crossbar (A) at the division 6 m.m. (the ground-glass holder is 6 m.m. behind the index) on the main bar of the testing bench—set the microscope table so that it will read near the zero line—focus the microscope table upon the plate, using the cross wires placed in the ground-glass holder. This should be done by means of the upper rack and pinion (C) which moves the microscope only. The plate with cross wires may now be removed and the aerial image only examined, but the focus of the microscope when once set must not be disturbed. Screw the photographic lens which is to be examined into the holder; the level surface of the screw rings being away from the microscope. Slide the lower lens holder platform (B) backwards and forwards until the image of a distant object is about in focus when viewed through the microscope; then carefully set the lens holder to the nearest division on the main bar. Focus the image of a distant object by means of the rack and pinion (D) which moves the microscope table, and observe whether the image moves when the upper lens holder platform (F) is rotated on its fitting (E); if it does, rack the upper portion of the platform of the lens holder forwards and backwards, until a position is found at which the rotation of the lens leaves the image viewed through the microscope perfectly stationary.

The microscope eyepiece is provided with cross wires by which any movement can be immediately detected. The simplest method is as follows:—Place the central platform (F), so that it is in adjustment with the main bar, and bring an object upon the cross wires of the microscope by shifting the whole table or the object. Then swing the upper platform say 10°. If the lens is not adjusted the object will no longer be on the cross wires—rack the lens holder backwards or forwards till the object is again on the cross wires when it has been refocussed by the microscope table adjustment (D); it will be found to be at the position of stationary rotation.

The back equivalent plane is now over the centre of rotation (E) of the lens holder, and its distance from the screw shoulder of the lens is given by reading the scale (F) on the upper platform (figure 151) of the lens-holder.

The equivalent focus of the lens is given (a distant object having been accurately focussed by the milled head D), by taking the reading on the main bar of the testing bench, and adding or deducting the reading on the scale (F) of the microscope table (G). If this be on the plus side of zero it must be added, or upon the minus side it must be deducted. *Note.*—If the lens possesses "distortion," when the position is found at which a small rotation will not move the image, rotation through a large angle will produce a slight deflection. In this case the lens should only be rotated through a small angle.

(II.) The Magnifying Power Method.—If two objects can be erected at a sufficient distance from the apparatus to rank as distant objects say 100 times the focus of the longest lens to be tested (about 100 yards), and if the distances of these objects can be determined, the method is one of the simplest and most accurate that can be adopted. Suppose two objects or marks be placed in a plane 100 yards from, and at right angles to the axis of the lens, and if the distances between the two objects be a definite ratio to their distance away, the focus can be instantly taken as follows:—Suppose the objects are 50 yards apart, that is, one half of the distance away, the images of these objects will be half the equivalent focus of the lens from each other.

To measure the focus, the lens must be focussed for 100 yards; the microscope table (H) should now be run laterally, to the right, along the crossbars, till one of the objects is on the cross wires of the microscope; note the reading on the crossbar scale, then run the microscope table (H) to the left, until the other object is on the cross wires, and the distance between the two positions of the microscope table read on the scale of the crossbar (A) gives half the equivalent focus.

If the objects can be permanently erected, the focus of a lens can be taken at any time in a few seconds. If the object had been 25 yards apart, instead of 50, the reading would have been a quarter the equivalent focus of the lens. The only objection to this method is that its accuracy depends upon the absence of distortion, and is not suitable for single view or uncorrected single lenses.

Where it is only possible to erect the objects at a moderate distance from the lens, say 25 feet, a true result may be obtained by a correction made as follows:—Divide the distance of the object from the lens by the focus given through the above method, deduct one from this result, and divide it into the focus, deduct the result obtained from the focus given, and this will be the true equivalent focus, to a very close approximation. For example: Suppose a lens gives a focus of 10 inches for the object placed at 25 feet—25 feet (300 inches) divided by 10 inches is 30, deducting 1 leaves 29—29 divided into 10 inches gives ·345 inches, which deducted from 10 inches gives the true equivalent focus of 9·655 inches. This result is accurate to about $\frac{1}{5}$ per cent., and if the distance had been 50 feet instead of 25, would have been practically exact.*

This correction may be algebraically written thus:—

d = distance of objects from lens.
x = focus obtained by method (B).
f = true equivalent focus.

$$f = \chi - \frac{\chi^2}{d - \chi}$$

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* A modification of this method can be employed in connection with a collimator; if a disc with two small apertures be placed in the exact focus of the object glass of the collimator, and if these holes are an exact fraction of the focus of the object glass of the collimator, the distance apart of their images will be the same fraction of the equivalent focus of the lens being tested. Considerable accuracy is required with adjustments when employing this method, but it is useful for telephoto lenses which include only a small angle of view.

(III.) The Symmetrical Image Method.—Place in the ground-glass holder a plate with fine wires stretched across it or a glass disc with a design or series of square rules upon it. Place upon a holder at the other end of the testing bench and beyond the lens an exactly similar disc with the same design. Then shift the position of the lens and screen until the image of the one screen is focussed upon that viewed by the microscopic, and is of exactly the same size. To obtain this result the two screens have to be at equal distances from the lens. Having found the correct position, note the reading of the cross-bar (A) upon the main bar, and remove the screen which is beyond the lens, and without moving the lens move the crossbar towards it until a distant object is in exact focus; the amount moved is the equivalent focus of the lens. The length of the apparatus allows of the use of this third method for lenses up to about twelve inches focus; by the two other means lenses up to 40 inches focus may be measured.

2. To determine the Position of the Equivalent Planes.—If the position be found at which the lens can be rotated while the image of an object in focus remains stationary, as explained in the first method of taking the equivalent focus, the scale (F) on the upper platform of the lens carrier gives the distance of the back equivalent plane from the shoulder of the lens screw. The front equivalent plane may in like manner be obtained by removing the whole lens carrier with lens attached and placing it on the bar in a reversed position and making the adjustment again.

3. To determine the Effective Aperture of the Diaphragm.—It is assumed that the equivalent focus of the lens has already been determined by one of the methods given. It is now necessary to measure the diameter of the bundles of incident light admitted by the diaphragms. In the case of lenses which have their stop in front of the lenses, it is only necessary to measure the diameter of such stops, as it is these stops which define the size of the incident bundles of light. These diameters divided into the equivalent focus of the lens, give the focal aperture of the lens. Thus a 12-inch focus lens provided with a stop in front of it, with an aperture of 1½ inches, will have a focal aperture of f/8.

To measure the effective aperture of a diaphragm which is behind any of the lenses, focus the lens for a distant object. Then insert in place of the ground-glass in the ground-glass frame (I), a plate with a small aperture. Swing the microscope (K) to one side, and place a gas jet or other source of illumination behind the aperture. Now upon the further side of the lens, and as close to it as may be convenient, place the Iris diaphragm (P), wide open, with the plate of ground glass supplied for the purpose clipped on to its face. An illuminated disc will appear upon the ground glass, which corresponds to the size of the bundle of parallel light, which would, under normal circumstances, pass into the lens to form an image of a point in its focal plane. The iris diaphragm may be now closed down till it just includes the illuminated disc, and the diameter read upon the scale attached. This diameter divided into the equivalent focus, gives the focal aperture of the diaphragm.

If it is required to obtain the focal aperture of a lens for copying at close quarters, the same plan is adopted, except that the lens is first focussed for the distance at which the object is placed—the measurement of the illuminated disc must be made on the front surface of the lens with calipers, a tissue paper screen having been placed upon the front of lens. The diameter of this circle may also be read by using a telescope objective screwed into the microscope in place of the microscope objective, and sliding the microscope table on the crossbar, till the two edges of the disc are alternately on the cross wires of the eyepiece, noting the distance travelled, but for this purpose the illuminated point must be arranged on the far side of the lens.

A second method of obtaining the focal apertures is as follows:—

If a distant point of light, such as a star or a small aperture with a strong light behind it, be placed in the line of vision of the optical bench, the focal apertures can be instantly read off as follows:—accurately focus the light and read the scale on the microscope table; rack the microscope forward a definite distance, say 50 mm., and the point of light will have changed into a disc, slide the microscope laterally on the crossbar until one edge of this disc is on the cross line in the microscope eyepiece, then slide it till the other side of the disc is on the cross wire of the eyepiece, noting the readings of the crossbar scale; the distance between the two readings divided into the definite distance travelled forward, in this case 50 mm., gives the focal aperture of the diaphragm. A "collimator" may be used to make this measurement, but there are grave practical disadvantages connected with its use; for one thing it must be very large, and the collimator must be sufficiently accurate to ensure a correct result, this renders such an instrument expensive.

(4) The Diameter of the Maximum Circle of Illumination.—(A) To determine this diameter, focus the lens upon the testing bench so that distant objects are sharp in the microscope. (It is assumed that the microscope is always kept focussed upon the plane of the ground-glass holder. It is better to focus the microscope upon this disc than upon the ground glass, as the latter, is of perceptible thickness, it slightly alters the focal distance of the microscope when it is removed.) Then slide the microscope table backwards and forwards on the crossbar until the two edges of the circle of illumination are successively brought on the cross wires of the eyepiece. The diameter of the maximum circle of illumination is read off the scale on the cross bar. To turn this into angular measurement: —

If d = diameter of the circle of illumination.
,, f = equivalent focus of the lens.
,, θ = angle.

$$\frac{d}{2f} = \tan\theta \text{ or } \tan\frac{d}{2f} = \theta.$$

(B) The angle can be read off direct upon the scale on the rotating portion of the lens-holder, if the back equivalent plane be placed over the rotating axis, and the microscope table fixed at zero on the cross barscale.

THE DIAMETER OF EQUAL ILLUMINATION WITH VARIOUS APERTURES.

For this purpose the microscope is turned into a telescope, by replacing the microscope objective by the telescope object glass, —the position where the stop of the lens ceases to appear as a circle is noted for the different sized apertures. It is evident that a circle will always appear as an ellipse when viewed obliquely, but for practical purposes this inequality of illumination is the least important factor. The position that should be recorded is that point where the edge of the lens or some portion of the mounting commences to reduce the area of the cone of illumination. This describes the inequality of illumination due to the construction of the lens, the other defect being a fixed quantity which is not influenced by design or manufacture.

THE USE OF A COLLIMATOR.

It may be well to point out the cases in which a distant object may be replaced without danger of a serious error, by a collimator. A collimator is an object in the focus of a corrected lens which emits a parallel beam of light, thus simulating a distant object. In testing the corrections of a lens it is seldom advisable to make use of it, because the corrections of a collimator are not always perfect, and introduce additional errors; but in method (I.) and the latter part of method (III.), for taking the equivalent focus in determining the position of the equivalent planes, it may be used. A well corrected collimator may be used also, in method (II.) for determining the maximum circle of illumination, if it be as large as the lens examined it may be employed. It is not recommended for determining the effective aperture of a lens, because in this case, it must be very perfectly corrected for central, spherical, and chromatic aberration, and must have an aperture at least as large as that of the lens under examination.

THE CENTRAL CORRECTIONS.

(1) Chromatic aberration.
(2) Spherical aberration.
(3) Freedom from striæ.
(4) Freedom from strain in mounting.
(5) Perfection of the surfaces.
(7) Resultant definition (stop required).

THE EXAMINATION OF THE CENTRAL CORRECTIONS.

In testing both the central and oblique corrections of a lens, it is necessary to bear in mind the purpose for which the lens is to be used. A lens which is corrected for distant objects will not be so perfectly corrected for copying full size. In most cases, this is of little consequence, because in increasing the conjugate focus in order to sharply define near objects, the focal aperture of the lens is so much reduced, that any slight imperfection in the corrections of a lens will be more than compensated for by the smaller aperture thus employed. For process work or copying, the lens must, however, be specially corrected for objects at small distances from the camera, and all tests of such a lens must be carried out upon objects at a short distance—probably if the tests are placed at a distance of three times the focus of the lens, this would be the best average position at which to judge of its qualities. It is for this reason that we prefer to make the tests of the oblique corrections of a lens by sliding the microscope table to the right or left upon the crossbar of the apparatus, and not by rotating the lens while the microscope remains stationary. The object for which a copying lens is used, is to reproduce flat subjects such as engravings, pictures, or maps and the edges of such subjects are further from the lens than the centre. If the method of swinging the lens is employed, the test object being examined is always at the same distance. When the test object is at a great distance this method produces no perceptible error, but is useless for testing a copying lens, moreover this method of rotating the lens cannot be employed except for lenses where the equivalent planes are in the neighbourhood of the diaphragm. A single view lens cannot be tested by rotating the lens, neither can a Cooke lens, whose back equivalent plane is on a level with the front surface.

(1) Chromatic Aberration.—I. Place a small aperture or pinhole in front of a brilliant source of light at the distance for which the lens is to be tested. For general work at a distance, say 25 to 50 times the focus; for a copying lens at a distance three times the focus.

Adjust the microscope table to zero by the milled head (D), and focus the microscope by the milled head (C) to the disc with cross wires, which latter should then be removed.

Point the testing bench at the illuminated aperture till the image produced by the lens to be tested, is in the centre of the field of the microscope; accurately focus the image and place a direct vision spectroscope prism over the eyepiece of the microscope—the image of the point will now appear as a coloured line. If the lens be absolutely corrected for colour it will appear as a fine line of the same thickness throughout its length, but of different colours (A figure 153).

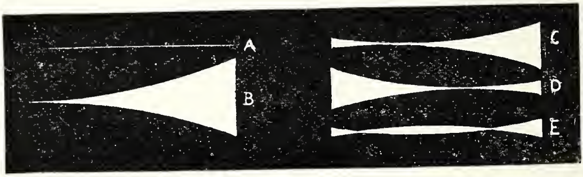

Figure 153.

If the lens be entirely uncorrected it will appear when the red light is in focus as a fan (B figure 153).

If now the yellow be focussed, it will appear as C, figure 153.

If the green be focussed it will appear as D, figure 153.

Thus the exact focus of each coloured light can be obtained, and its position noted on the scale of the microscope table.

When a lens is corrected for chromatic aberration, but has a slight residual secondary spectrum, the appearance will be as E, figure 153, and the amount of outstanding aberration can be measured by the same process. This method has the disadvantage that when the object is at a distance of from 25 to 50 times the focus a very powerful illumination is required—it is the best method to employ where a sufficiently brilliant light is available.

II. This method is the same as the last, except that instead of the spectroscope prism, three troughs containing monochromatic solutions are employed in a sliding frame between the object glass and the eyepiece of the microscope, they can be rapidly slid into the field, and the change of focus observed for the different colours.

(2) Central Spherical Aberration.—The apparatus is arranged in the same manner as in testing for chromatic aberration, and a similar point of light is examined but without the use of the spectroscope or monochromatic troughs. If the correction for chromatic aberration is so deficient that a coloured image is seen, a monochromatic trough may be employed. In fact, as the green and blue rays are those most chemically active, it is always advantageous to employ a green solution when the illuminant is powerful enough to admit of it.

By means of the Iris diaphragm (L) and a series of discs placed on the clips of the Iris frame, a series of annular openings are made. The rings thus formed are placed as close as possible to the lens, and the focus for the different portions of the lens recorded. In this way the refraction of the entire lens may be mapped out and, if desired, plotted on a curve. In most photographic lenses this correction has been effected more or less, and it is generally sufficient to examine the image without making use of the annular apertures. For this purpose the microscope should be focussed first beyond the focus, and the disc representing a section of the cone of light which forms the image examined; the microscope should then be rapidly focussed back beyond the focus and the disc representing a section of the cone of light beyond the focus examined. If the two discs appear equally bright throughout and of equal intensity, especially at their margins, the spherical aberration of the lens is fairly well corrected. If the margin of the disc, when nearer to the lens is much more definite than that of the disc on the outside, it is clear the margins of the lens are transmitting light to a different focus than that to which the centre is.

Figure 154 represents a well corrected lens, the whole light passing approximately through a point. It is evident that at the section A and B of the cone of rays the distribution of the light will be similar, and the two sections will be identical in appearance.

Figure 155 represents a badly corrected lens, where the marginal rays come to a shorter focus than the central rays. It is evident that the edge of the disc given by the section A will have more than its share of light and the disc will have a sharply defined bright edge, whereas the edge of the disc at B will have only an indistinct hazy outline and a more intense central illumination.

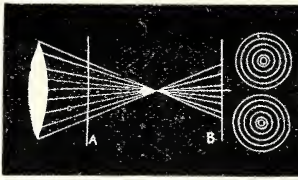

Figure 154.

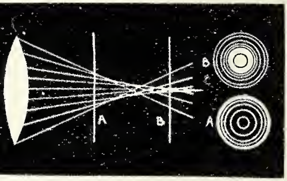

Figure 155.

This test, when employed with a sufficiently small and brilliantly illuminated point of light, is particularly sensitive, as very slight differences in the appearance on the opposite sides of the focus can be readily detected. It is also specially useful because it forms a means of examining the lens for the three following defects.

(3) Examination of the Lens for Striæ.—As mentioned before, prominent veins or striæ in the glass can be seen by placing the eye in one conjugate focus of the lens and a lamp or other illuminant in the other, the whole lens appears a blaze of light, and feathers or veins will be readily detected. Fine striæ, however, which cannot be detected in this manner will be readily seen by examining the discs on either side of a focussed point of light, as explained above. It is necessary that the lens should be approximately corrected for central spherical aberration, and the better the correction in this respect the more sensitive is this test for striæ. Any imperfections which do not show upon a careful and thorough examination of this kind may be safely neglected as harmless.

(4) Freedom from Strain in Mounting.—If, upon examination of the discs upon either side of the focussed image, they do not appear circular, it may be caused by the lenses being under tension in the lens cells, by being held too tightly ; this often shows as an appearance of two ellipses on either side of the focus in directions at right angles. The lens has, what is technically known as a twist.

(5) Perfection of the Sphericity of the Surfaces.—Many of the defects due to bad workmanship may be detected by this test. If the discs, instead of being circular are irregular, one or more of the surfaces are not truly spherical. It is inconvenient in testing a lens to take it to pieces, and test its surfaces by proof glass or reflection methods. If properly carried out this test makes a very perfect method of testing the complete lens.

It is important, when examining a lens by this means, that the air from the illuminated point to the observer's eye should be reasonably isothermic. When the test point of light is at a distance it is essential that the line of sight is not over a stove or gas burner, which would produce a flickering in the air that would spoil the definition. In our own factory, where the line of sight passes through a heated workshop, a tube 12 inches diameter, 100 feet long, coated outside with a layer of asbestos, is erected to preserve a homogeneous column of air.

(6) Central Definition Test.—The foregoing tests will determine the errors that may exist in a lens, and if carefully executed will detect their presence, even in very minute degrees. A photographic lens, however, requires so many conflicting errors to be corrected that it may be advisable to compromise to a certain extent.

Although the central aberration should be sufficiently eliminated to avoid lack of central definition, certain slight errors, not incompatible with this result may be left, to render the correction of some of the oblique aberration more possible. It therefore becomes necessary to fix a standard of central definition.

If a point be represented by a circle not larger than 1-200th of an inch in diameter, the picture may be considered reasonably sharp. For a lens which is to be used with a telephoto attachment, magnifying the original image ten times, this circle should not be more than 1-2000th of an inch, in the original image. For short focus lenses, therefore, up to say 10-inch focus, this standard may be asked for in the most perfect lenses. To test the defining power of a lens a series of gratings of different sizes should be placed at a distance, with an illuminant placed behind them and the image of them examined with the microscope, the ground glass having been removed. If a grating be made with black lines 1-10th of an inch thick and 4-10th of an inch apart, and placed 100 feet from the lens, the image of the line given with a 6-inch focus lens will be 1-2000th of an inch. If this image be examined with a microscope having a magnifying power of from 20 to 40 diameters, and is clearly discernable, the standard is reached. The standard of definition may be lower than this for most purposes, although the most perfectly made lenses of short focus will readily give this resolving power.

THE OBLIQUE CORRECTIONS.

(1) Curvature of field.
(2) Radial and tangential astigmatism.
(3) Zonal aberration.
(4) Oblique chromatic aberration.

(1 and 2.) Curvature of field and astigmatism may be conveniently tested together, and a diagram prepared which shows the characteristics of the lens in these respects. As before mentioned, copying lenses should be tested by means of a diagram placed at a distance of about three times the focus of the lens. This diagram may be made in the form of any convenient design placed at right angles to the axis of the lens. Portions of a convenient design have been reproduced in plates IV., V., VI., XI., XII., XIII., XIV., XV., and XVI.

When the lines A B measure 100 mm. in the focussed image, the diagram is at a distance from the lens of three times its focus.

The first adjustment to be made is to move the testing bench towards the diagram until the image of the distance A B is found to measure 100 mm., ascertain this by shifting the microscope backwards and forwards on its crossbar E, to 50 mm. on either side of the centre. The exact adjustment of this is only important for making comparison between various lenses of different foci. The next adjustment is to ascertain by moving the microscope table to two positions, an equal distance from the centre on either side, that the diagram is in focus equally at the two positions. When this is so, the test diagram is at right angles to the optic axis of the lens.

The chart may now be prepared on squared paper. Focus the test diagram at the centre or Zero mark of the scale. Then move the microscope table to one side a fixed amount, say 50 mm., and record the focus first for horizontal and then for vertical lines, which can be dotted on the squared paper. This can be done for any number of positions, and the curves of radial and tangential astigmatism plotted out. The least circle of confusion lies between these curves, and its focus is the curve by which the curvature of field is expressed; the test diagram is pierced with a series of minute holes by which the position of this circle can be obtained. The diameter of the circle of least infusion can be measured by a micrometer placed in the focus of the microscope and recorded on the chart.

In making the chart for a lens focussed to distant objects, an illuminated grating, or small series of gratings, and an aperture, or series of apertures, are placed at a distance of not less than 25 feet, preferably 50 feet. The lens is then placed as described, so that its back equivalent plane is over the centre of rotation. The testing bench is then pointed to this grating, and the lens being swung say every 5°, the position of the foci for radial and tangential lines are recorded. These distances may be calculated

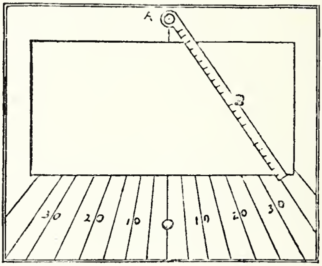

Figure 156.

for the purpose of making a diagram, or a graphical method may be employed as follows: A drawing board is provided with a centre A (figure 156), upon which swings an arm B, divided in $\frac{1}{2}$ mm. On the drawing board are a series of divisions representing every 5° of rotation of the arm B; the squared paper is affixed to the board and the central focus marked upon the paper, the arm A being placed at O. The arm is placed in turn to the degree of rotation of the lens and the foci of the radial and tangential astigmatism, and the least circle of confusion are marked off.

(3) Zonal Aberration.—This defect is tested by placing the microscope table to one side of the crossbar, or retaining the microscope in the centre of the crossbar, meanwhile by swinging the lens on its back equivalent plane, and, observing the image of a distant point of light. By means of annular diaphragms specific rings of the lens can be examined, and the foci of the different zones may be measured by the methods already explained.

(4) Oblique Chromatic Aberration is tested by the means indicated for central aberration, but at the same time swinging the lens to obtain oblique pencils. As zonal aberration is usually present and prevents the obtaining of a point image, it is generally advisable to examine only a small part of the lens at once, by using the Iris diaphragm in front of the lens.

Depth of Focus.—In order to test the depth of focus or depth of definition, a standard of definition must be laid down. It is considered by most authorities that an object which measures 1-200th of an inch in the image should be clearly visible. If, therefore, a test is made as to what distance the microscope table can be focussed backwards and forwards without obliterating a grating whose image is 1-200th of an inch per line, the depth of focus can be measured. This quantity is almost the same in the centre of the field for all lenses of the same focus and aperture, varying only with the correction for spherical aberration. The marginal depth, however, is a varying amount, and two additional lines may be added to the chart to express the limits of the depth of focus throughout the field. The amount of this depth, or the area included between the lines, is sometimes called the Focal Volume of a lens.

In order to readily set a grating at such a distance that its image is 1-200th of an inch, a micrometer eyepiece is supplied, each division of which represents 1-100th of an inch in the image.

Another method, that of using a point of light on the object, may be employed. If this point is sufficiently small to give an almost punctiform image, the microscope may be racked forwards and backwards till the disc measured by the microscope is 1-200th of an inch in diameter and the position recorded. If the image of the disc has a small size, say 1-100th of an inch, this may be measured first, and the microscope may be racked forwards till it appears this size, added to 1-200th of an inch. This method is unsatisfactory if the lens possesses zonal aberration, and the well-known method of examining a bar of thin metal at 45° which, by rotation, can be made to give an image of the required size, is preferable.

Centring.—The determination of the axis of the lens with reference to its mounting may be ascertained by revolving the lens upon the axis, and finding whether it has to be shifted on the axis of the lens table so that the image shall remain stationary during revolution.

The important test, however, to find out whether the various surfaces have all their centres of curvature upon a common axis. This is best tested by the method used at Kew of examining with a telescope object-glass in the microscope, whether when viewing a light through the lens, all the images reflected from the various surfaces can be made to lie in one straight line.

Another method is to place a small light at one end of the crossbar and move the telescope to the other end, focussing each reflected image in turn, and by revolving the lens on its own axis to ascertain whether the reflected images remain stationary. Any single surface that is out of centre can thus be ascertained.

Distortion.—For the determination of this error a bracket is supplied to the testing bench, which will carry the entire lens carrier in a plane at right angles to the bench. This places the axis of rotation of the lens (E) in a horizontal instead of a vertical position. The lens to be examined is now adjusted by the rack and pinion (M) so that it rotates upon its back equivalent plane. It is now swung to any desired angle, and a distant horizontal line is examined. A ground glass with ruled divisions is placed in the ground-glass holder and a low power eyepiece, magnifying 4 diameters, placed in the microscope. The microscope table having been focussed to the distant line, is slid to the right or left on the crossbar, and the height of the line noted at various positions. If the lens is free from distortion the height will be the same throughout. If distortion is present its amount is determined by the number of divisions above or below the centre at which it appears, at the margins of the field.

Any of the phenomena of oblique or central aberration may be photographed upon a magnified scale by means of a small plate holder which fits the eyepiece end of the microscope. A ground glass, which has the same register as the camera, is supplied in a fitting. This must be slipped into the microscope draw-tube and the image focussed upon this ground glass, after which it can be replaced by the plate holder and the photograph taken.

The Intensity Test, as devised by Sir W. Abney, may be carried out on this bench as described in Mr. Cole's treatise on Photographic Optics, and the relative intensities of illumination given by a lens at different portions of the field obtained, but as these intensities are only visual intensities, it is a test that is not frequently made use of.

It requires a set of screens and lamps, which can be successfully used on brackets sliding upon the main bar of the testing bench.

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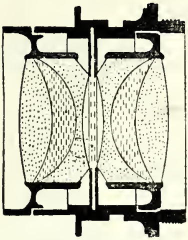
and 3, Amen Corner, London, E.C.

BECK LENSES.

UNIVERSAL ORTHOSTIGMATS.

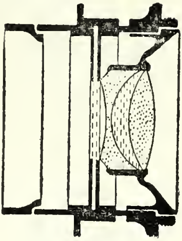


(Complete Lens.)

SERIES I.

f/6·3.

The BECK
STEINHEIL
ORTHO-
STIGMAT.



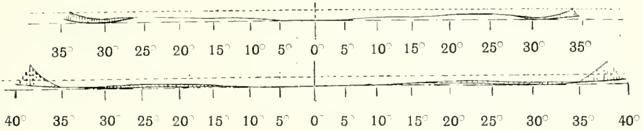
Single combination.

PRICES OF LENSES. SERIES I.

Aperture: Nos. 1-5, f/6·3; Nos. 6-8, f/6·8; Nos. 9-11, f/7 to f/8.

No.	Aperture.		Focal Length.		Recommended for plate.	Plate covered sharply.			Price.
	In.	Mm.	In.	Cm.		f/6·2.	f/20.	f/40	
0	⅛	3	1	2·5	—	⅝ × ⅝	¾ × ¾	1⅛ × 1⅛	£4 7 6
0a	¼	6	2	5	—	1⅝ × 1⅝	2 × 2	2 × 2½	4 7 6
0b	⅜	10	2¼	5·4	—	1⅞ × 1⅞	2⅛ × 2⅛	2¼ × 2½	4 0 0
0c	½	13	3⅛	8	—	2½ × 3½	1¾ × 4	3¼ × 4¼	4 7 6
1	9/16	14	3½	9	3¼ × 3¼	3¼ × 3¼	4¼ × 3¼	4¼ × 3½	4 10 0
2	⅝	16	4⅛	10·5	4¼ × 3¼	4¼ × 3¼	4¼ × 3½	6 × 4	4 15 0
3	¾	18	4¾	12	4¼ × 3¼	4¼ × 3½	5 × 4	7½ × 5	5 0 0
4	⅞	22	5 15/16	15	5 × 4	6 × 4	7½ × 5	8½ × 6½	6 0 0
5	1 1/16	27	7¼	18	6½ × 4¾	6½ × 4¾	8 × 6	9½ × 7	7 5 0
6	1¼	31	8¼	21	7½ × 5	7½ × 5	8½ × 6½	11 × 8¼	8 10 0
7	1 7/16	36	9½	24	8½ × 6½	8 × 6	9½ × 7	12 × 9½	10 10 0
8	1⅝	41	11	28	8½ × 6½	8½ × 6½	11 × 8¼	14 × 11	13 0 0
9	2⅛	53	14¼	36	10 × 8	10 × 8	12 × 9½	16 × 16	20 0 0
10	2⅞	72	19	48	12 × 10	12 × 9½	16 × 12	24 × 20	30 0 0
11	3 9/16	90	23½	60	15 × 12	16 × 12	20 × 16	28 × 24	45 0 0

* In Aluminium: £1 extra Nos. 0 to 8; £2 extra Nos. 9 to 11.



DIAGRAMS OF ASTIGMATISM.

The above diagrams represent actual tests of two Beck-Steinheil lenses taken at random. They show that the focal plane is almost mathematically flat for an angle of from 60° to 70°, and that there is no astigmatism except in the last 10° of their total illuminating area.

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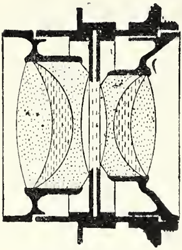
BECK LENSES.

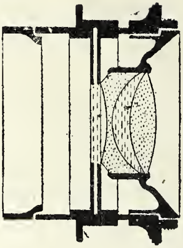
UNIVERSAL CONVERTIBLE ORTHOSTIGMATS.



(Complete Lens.)

SERIES II.

f/6·8, f/7·7.



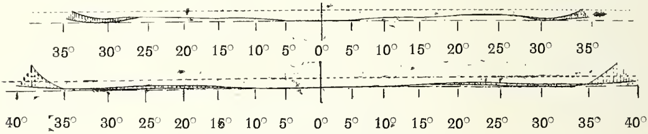
(Single combinations.)

THE BECK-STEINHEIL ORTHOSTIGMAT.

PRICES OF LENSES. SERIES II.

No.	Focus. Single Lens, f/12·6.		Combined Focus.	Aperture.	Size of Plate in inches.			PRICE* with Brass Mount.
	Back.	Front.			Focus most suitable for Plate.	Can be used at Full Aperture.	Plate covered at f/40.	
1a	6	7	$3\frac{7}{8}$	f/6·8	$3\frac{1}{2}\times3\frac{1}{2}$	$3\frac{1}{2}\times3\frac{1}{2}$	5×4	£4 15 0
1b	6	$8\frac{1}{2}$	$4\frac{1}{8}$	f/7·7	$4\frac{1}{4}\times3\frac{1}{4}$	$4\times3\frac{1}{4}$	$5\frac{1}{2}\times4\frac{1}{2}$	5 0 0
2a	7	$8\frac{1}{2}$	$4\frac{1}{2}$	f/6·8	$4\frac{1}{4}\times3\frac{1}{4}$	$4\frac{1}{2}\times3\frac{1}{2}$	$6\frac{1}{2}\times4\frac{3}{4}$	5 2 6
2b	7	10	$5\frac{1}{8}$	f/7·7	5×4	5×4	7×5	5 15 0
3a	$8\frac{1}{2}$	10	$5\frac{1}{2}$	f/6·8	5×4	6×4	8×5	5 17 6
3b	$8\frac{1}{2}$	$12\frac{1}{2}$	$5\frac{15}{16}$	f/7·7	6×4	$6\frac{1}{2}\times4\frac{1}{4}$	$8\frac{1}{2}\times6\frac{1}{2}$	6 10 0
4a	10	$12\frac{1}{2}$	$6\frac{1}{2}$	f/6·8	$6\frac{1}{2}\times4\frac{3}{4}$	7×5	9×7	7 0 0
4b	10	$14\frac{1}{2}$	$7\frac{1}{8}$	f/7·7	$6\frac{1}{2}\times4\frac{3}{4}$	7×5	$9\frac{1}{2}\times7\frac{1}{2}$	8 0 0
5a	$12\frac{1}{2}$	$14\frac{1}{2}$	$7\frac{3}{4}$	f/6·8	7×5	8×5	10×8	8 10 0
6a	$14\frac{1}{2}$	17	$8\frac{7}{8}$	f/6·8	$8\frac{1}{2}\times6\frac{1}{2}$	$8\frac{1}{2}\times6\frac{1}{2}$	12×10	10 0 0

* Price in Aluminium, £1 extra.



DIAGRAMS OF ASTIGMATISM.

The above diagrams represent actual tests of two Beck-Steinheil lenses taken at random. They show that the focal plane is almost mathematically flat for an angle of from 60° to 70°, and that there is no astigmatism except in the last 10° of their total illuminating area.

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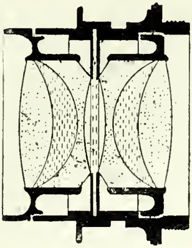
BECK LENSES.

PROCESS ORTHOSTIGMATS.

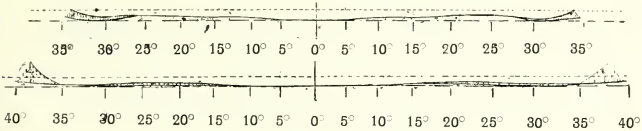
SERIES III. f/10.



THE BECK-STEINHEIL ORTHOSTIGMAT.

PRICES OF LENSES. SERIES III.

No.	Aperture.		Focus.		Size of Plate covered sharply.			PRICE.	With Best Quality Prism.	With Second Quality Prism.
	mm.	in.	cm.	in.	Copying full size.	Groups, f/10.	Land-scapes, f/56.			
7	35	1⅜	30	11¾	20 × 16	10½ × 8½	16 × 12	£14 0 0	£29 0 0	£18 10 0
8	45	1¾	40	15¾	24 × 20	13½ × 10½	20 × 16	20 0 0	40 0 0	26 0 0
9	58	2¼	50	19¾	28 × 24	16 × 12	24 × 20	30 0 0	55 0 0	39 0 0
10	70	2¾	60	23½	32 × 28	18 × 14	28 × 24	40 0 0	70 0 0	52 0 0
11	87	3½	75	29½	36 × 32	20 × 16	32 × 28	60 0 0	97 10 0	85 0 0
12	105	4⅛	90	35½	40 × 36	24 × 20	36 × 32	90 0 0	135 10 0	—



DIAGRAMS OF ASTIGMATISM.

The above diagrams represent actual tests of two Beck-Steinheil lenses taken at random. They show that the focal plane is almost mathematically flat for an angle of from 60° to 70°, and that there is no astigmatism except in the last 10° of their total illuminating area.

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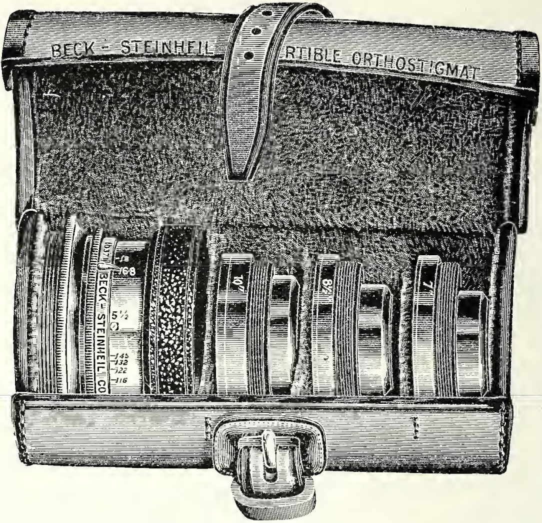
BECK LENSES.

SETS OF ORTHOSTIGMATS.



CONVERTIBLE SERIES II.

SETS OF ORTHOSTIGMATS.

SET No. I.—For plates 3½ × 2⅝ or 3½ × 3½.

½ Comb. of Lens No.	Focus.	Aperture.	Angle.	Plate covered.
1	6 in.	f/12·5	41°	5 × 4
2	7 ,,	f/12·5	36°	6½ × 4¾
3	8½ ,,	f/12·5	29°	7 × 5
1·2	3⅞ ,,	f/6·8	62°	3¼ × 3¼
1·3	4⅛ ,,	f 7·7	54°	4¼ × 3¼
2·3	4½ ,,	f/6·8	52°	4½ × 3½

PRICE . .. £8 0 0

SET No. II.—For plates 4¼ × 3¼.

½ Comb. of Lens No.	Focus.	Aperture.	Angle.	Plate covered.
2	7 in.	f/12·5	41°	6½ × 4¾
3	8½ ,,	f/12·5	36°	8 × 5
4	10 ,,	f/12·5	30°	9 × 6
2·3	4½ ,,	f/6·8	62°	4½ × 3½
2·4	5⅛ ,,	f/7·7	54°	5 × 4
3·4	5½ ,,	f/6·8	49°	6 × 4

PRICE £8 17 6

SET No. III.—For plates 5 × 4.

½ Comb. of Lens No.	Focus.	Aperture.	Angle.	Plate covered.
3	8½ in.	f/12·5	41°	8 × 5
4	10 ,,	f/12·5	35°	9 × 6
5	12½ ,,	f/12·5	30°	10 × 8
3 4	5½ ,,	f/6·8	62°	5 × 4
3·5	5 15/16 ,,	f/7 7	56°	6 × 4
4·5	6½ ,,	f/6·8	52°	6½ × 4¾

PRICE £10 5 0

SET No. IV.—For plates 6½ × 4¾.

½ Comb. of Lens No.	Focus.	Aperture.	Angle.	Plate covered.
4	10 in.	f/12·5	44°	9 × 6
5	12½ ,,	f/12·5	35°	10 × 8
6	14½ ,,	f/13	31°	12 × 10
4·5	6½ ,,	f/6·8	65°	6½ × 4¾
4·6	7⅛ ,,	f/7·7	59°	7½ × 5
5·6	7¾ ,,	f/6·8	54°	8½ × 6½

PRICE £12 12 6

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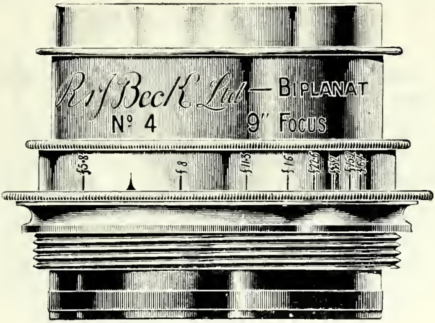
BECK LENSES.

BECK-BIPLANAT. SERIES I. f/5·8.



THE BECK-BIPLANAT (mounted in Brass and Magnalium).

Aperture f/5·8.

No.	Focus.	Focus of Back Combination.	Plate Covered. f/5·8.	Plate Covered. f/22.	Price.
1	4¼	8	3¼ × 3¼	4¼ × 3¼	£2 10 0
2	5	9	4¼ × 3¼	5 × 4	2 15 0
3	6	10½	5 × 4	6½ × 4¼	2 17 6
4	7	13½	5½ × 4¼	6½ × 4¾	3 2 6
5	8¾	16	6½ × 4¾	8 × 5	3 10 0
6	11	20	8½ × 6½	9 × 7	4 10 0
7	13	23	10 × 8	12 × 10	5 10 0
8	16	28	12 × 10	16 × 12	8 10 0

It gives better depth and covering power than a Portrait Lens, and need not be stopped down for this purpose.

At full aperture it is fast enough for extra rapid shutter exposures, and although it does not cover as well as the Orthostigmat, is sufficient for most of these photographs when the object of interest does not extend to the corners of the plate.

With stops f/8 to f/22 it is an excellent lens for landscape and pictorial photography. With small stops it will cover a wide angle.

Considering its extraordinary low price it may be recommended to all who do not wish to go to the price of an Orthostigmat, and should be chosen in preference to the Rapid Rectilinear types.

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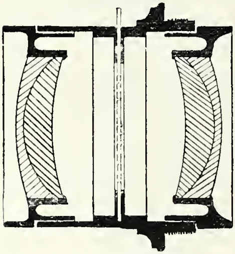
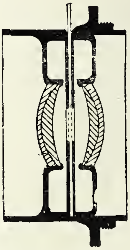
BECK LENSES.

AUTOGRAPH RAPID RECTILINEAR.

SERIES II. f/8.



(R.R. and M.A.R.)



(W.A.R.)

Aperture: f/8.

No.	Focus.	Plate covered, f/8.	Plate covered, f/22.	PRICE.
0	4¼	3¼ × 3¼	4¼ × 3¼	£2 5 0
1	5	4¼ × 3¼	5 × 4	2 10 0
2a	6	5 × 4	6½ × 4¼	2 15 0
2	7	5 × 4	6½ × 4¾	2 17 6
3	8¾	6½ × 4¾	8 × 5	3 3 0
4	11	8½ × 6½	9 × 7	4 0 0
5	13	10 × 8	12 × 10	5 0 0
6	16	12 × 10	16 × 12	7 15 0

Mid and Wide-Angle Autograph Rectilinear Lenses.

M.A.R. Aperture: f/11·5.

No.	Focus.	Full Aperture.	Small Stop.	PRICE.
1	3	3¼ × 3¼	5 × 4	£2 7 6
2	4	4¼ × 4¼	6½ × 4¾	2 10 0
3	5	5 × 4	7½ × 5	2 15 0
4	6	6½ × 4¾	8½ × 6½	3 0 0
5	7	7½ × 5	9 × 7	3 5 0

W.A.R. Aperture: f/16.

No.	Plate.	Focus.	PRICE.
1	5 × 4	3	£2 10 0
2	6½ × 4¾	4	2 17 6
3	8½ × 6½	5	3 5 0
4	10 × 8	6	3 17 6
5	12 × 10	7	4 4 0

A Standard Lens at a moderate price. Excellent for all-round work where price is a consideration.

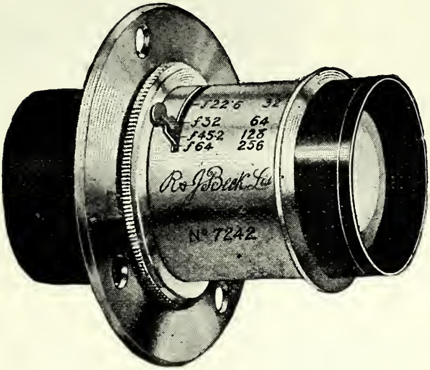
Fuller Particulars and Catalogues Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

BECK DOUBLE-APLANAT.

SERIES III.



BECK DOUBLE-APLANAT, f/7·7.

Aperture: f/7·7.

No.	Focus.	Plate Covered, f/7·7.	Plate Covered, f/22.	Price.
1	5	4¼ × 3¼	5 × 4	£1 10 0
2	6	5 × 4	6½ × 4¼	1 15 0
3	7	5 × 4	6½ × 4¾	1 17 6
4	8¾	6½ × 4¾	8 × 5	2 0 0
5	11	8½ × 6½	9 × 7	3 0 0

A first-rate Lens of the Rectilinear type—specially suitable for hand cameras.

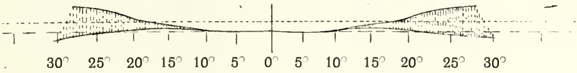


DIAGRAM OF ASTIGMATISM.

The above diagram represents actual tests of a Beck rectilinear lens taken at random from a number. It shows that the focal plane is flat for an angle of from 50° to 60°, and that there is no astigmatism for 20° of this total.

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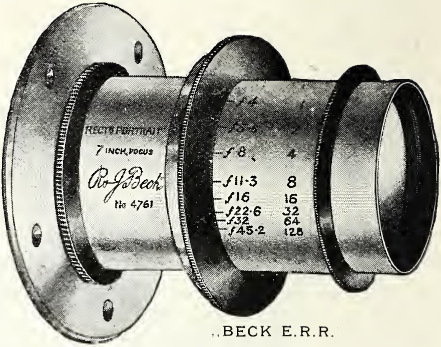
R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

THE BECK EXTRA RAPID RECTILINEAR.



Aperture: f/4.

BECK E.R.R.

No.	Equiv. Focus.	Size of Portrait.	Size of Views.	Prices.
2	7½	C.-de-V. and Busts ..	5 × 4	£8 10 0
3	9¾	C.-de-V. and Cabinets	6½ × 4¾	10 10 0
4	11¾	Cabinets	8½ × 6½	15 15 0
5	14	Panels	10 × 8	21 0 0

"AUTOGRAPH" NARROW-ANGLE SINGLE VIEW LENSES.

No.	Equiv. Focus.	Size of Plate.	Prices.
1	8½ in.	4¼ × 3¼ in.	£2 15 0
2	10½ ,,	5 × 4 ,,	3 5 0
3	12½ ,,	6½ × 4¾ ,,	3 10 0
4	15 ,,	8½ × 6½ ,,	4 5 0
5	18 ,,	10 × 8 ,,	5 5 0
6	23 ,,	12 × 10 ,,	7 0 0

"AUTOGRAPH" WIDE-ANGLE SINGLE VIEW LENSES.

No.	Equiv. Focus.	Size of Plate.	Prices.
1	5 in.	5 × 4 in.	£3 0 0
2	6½ ,,	6½ × 4¾ ,,	3 10 0
3	8½ ,,	8½ × 6½ ,,	4 0 0
4	10 ,,	10 × 8 ,,	5 0 0
5	12 ,,	12 × 10 ,,	6 10 0

SINGLE VIEW LENSES FOR HAND CAMERAS.

These Lenses have not been put separately on the market before, but we feel confident they will fill a want for a reliable single view lens. These Lenses are manufactured at our factory, and the price as will be seen, is very low. They are identical with those supplied in the celebrated Nos. 00 and 22 Frena Cameras, where their work is much appreciated.

Single View Lenses, f/11.

No	Focus.	Full Aperture.	Price.
1	4	3½ × 2½	£0 17 0
2	5½	4¼ × 3¼	1 2 6

All prices are strictly Nett Cash.

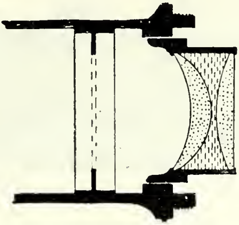
Fuller Particulars and Catalogues Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

TELEPHOTO LENSES AND ATTACHMENTS.

SERIES I., II. and III.



THE BECK-STEINHEIL TELEPHOTO ATTACHMENT.

(For any lens.)

PRICES OF SERIES I. STANDARD POWER.

No.	Negative Element.	Diameter of Element.	Focus of Element.	Suitable for Lens of Foci.	For Beck-Steinheil Orthostigmats.	PRICE in Brass.	PRICE in Magnalium.
1	No. I.	·905″	1·9″	4″ to 5½″	Nos. 2a, 2b, 3, 3a	£4 0 0	£5 0 0
2	.. Ia. or II.	1·259″	2·8″	5″ to 6½″	.. 3b, 4, 4a	4 0 0	5 0 0
4	.. II.	1·259″	2·8″	6″ to 8″	,, 4b, 5. 5a	4 15 0	5 15 0
5	.. IIa.	1·456″	3·3″	8″ to 9½″	,, 6	5 10 0	6 10 0
6	.. III.	1·653″	3·8″	9″ to 10½″	.. 7	6 0 0	7 0 0
7	,, III.	1·653″	3·8″	10″ to 13″	,, 8	7 0 0	8 0 0
8	,, IV.	2·440″	5·5″	13″ to 15″	.. 9	8 0 0	9 0 0

These Telephoto Attachments can be supplied either in Brass or Magnalium, with a rack and pinion attachment, **and fully engraved with the magnifying power.** The camera extension and circle of illumination can be found by reference to pages 247 and 248.

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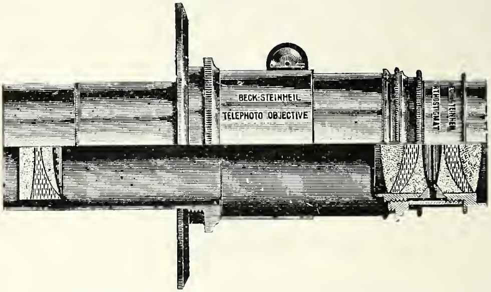
BECK LENSES.

Telephoto Lenses and Attachments.

SERIES II. AND III., HIGH AND LOW POWER.



The Beck-Steinheil Telephoto Attachment
shown fitted to a Beck-Steinheil Orthostigmat positive.

Prices of Series II., High Power.

No.	Negative Element.	Suitable for Lens of Foci.	For Beck-Steinheil Orthostigmats.	Price in Brass.	Price in Magnalium.
1	No. I.	7″ to 9″	Nos. 5, 5a, 4a, 4b, 6	£4 15 0	£5 15 0
2	No. II.	9″ to 12″	Nos. 7 and 8	5 10 0	6 10 0

Prices of Series III., Low Power.

No.	Negative Element.	Suitable for Lens of Foci.	For Beck-Steinheil Orthostigmats.	Price in Brass.	Price in Magnalium.
1	No. I.	3″ to 4¼″	Nos. 1, 1a, 1b, 2	£4 0 0	£5 0 0
2	,, II.	4½″ to 6″	,, 3, 3a, 3b	4 10 0	5 10 0
3	,, IIA.	6″ to 7″	,, 4, 4a	5 0 0	6 0 0
4	,, III.	7″ to 8½″	,, 4b, 5, 5a	6 0 0	7 0 0
5	,, IV.	8½″ to 11″	,, 6, 7, 8	7 5 0	8 5 0

These Telephoto Attachments can be supplied either in brass or magnalium, with a rack and pinion attachment, **and fully engraved with magnifying power.** The camera extension and circle of illumination can be found by reference to pages 247 and 248.

Fuller Particulars and Catalogues Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

Extensions and Circle of Illumination for Standard Power Telephoto Attachments and Beck-Steinheil Orthostigmats.

		ORTHOSTIGMAT f/6·3.						
Magnification.		3	4	5	6	7	8	9
		Focus 4¾	Focus 5 1/16	Focus 7⅛	Focus 8¼	Focus 9½	Focus 11	Focus 14
Element.		I.	II.	II.	IIa.	III.	III.	IV.
3	a	3½	4⅛	7⅛	8⅝	10¼	11⅛	15
	b	14¼	18	21½	24¾	28¾	32½	42½
	c	2⅜	3⅛	4¼	4¾	5½	6	9½
5	a	7⅛	8¼	12¼	14¼	16½	18⅛	24¾
	b	23½	29⅞	35⅞	41⅜	47¼	54	70
	c	4¼	6	8¼	9 1/16	9¾	10⅝	16½
8	a	11¼	14¼	18½	21¾	25⅛	28¾	42½
	b	37¾	47¼	57	66¼	75⅝	86¼	113½
	c	7⅛	9⅞	13	15¾	17¾	21¾	27½
10	a	14¾	18⅛	24½	27½	33½	37½	51¼
	b	47¼	59	71	82¾	94½	108⅜	142
	c	9½	11⅞	17	18½	19¾	25⅝	35½

Magnification of Low-Power Element with No. 5 Orthostigmat f/6·3.

3			4			5			8		
a	b	c	a	b	c	a	b	c	a	b	c
7½	21½	6½	12	28½	9½	16¼	35⅞	12¼	30	57	21

Magnification of High-Power Element with No. 5 Orthostigmat f/6·3.

8			10			15			20		
a	b	c	a	b	c	a	b	c	a	b	c
12	57	5½	16	71	9½	22	107	12	29½	142¼	15½

a—Camera Extension. b – Equivalent Focus. c—Diameter of Image, sharp.

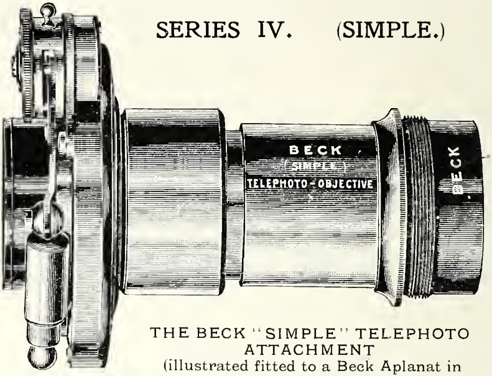
Full Catalogues Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

TELEPHOTO LENSES AND ATTACHMENTS.

SERIES IV. (SIMPLE.)



THE BECK "SIMPLE" TELEPHOTO ATTACHMENT
(illustrated fitted to a Beck Aplanat in Bausch & Lomb shutter).

Telephoto work is not confined to the users of the most expensive attachments, much can be done, particularly in the early days, with a simpler, if less perfect, instrument. The negative element is composed of two glasses, as against three in the Beck-Steinheil orthostigmat attachment.

This attachment has been brought out for use on cameras having only short extensions, and fitted with Bausch & Lomb shutters. The ordinary lens is unscrewed from the camera, and this little attachment screwed on behind it, focussing can then be accurately carried on by pulling or pushing the shutter and lens backwards or forwards. It gives magnification up to 4½°, and can be used with any lens.

No.	Element	For Lens of Focus	Diameter of Screw of Positive.	Price.	Rack and Pinion Extra
1	I.	4″ to 6″ in 5 × 4 B. & L.	or flanges up to 1½″	£1 15 0	10/0
2	I.	5″ to 7″ in 5 × 4 B. & L.	or flanges up to 1½″	1 15 0	10/0
3	II.	6″ to 9″ in 5 × 4 B. & L.	or flanges up to 1½″	2 0 0	10/0
4	II.	6″ to 9″ in 7 × 5 B. & L.	or flanges up to 2″	2 0 0	10/0
5	II.	6″ to 9″ in 9 × 7 B. & L.	or flanges up to 3″	2 10 0	12/6
6	II.	4″ to 7″ in 7 × 5 B. & L.	or flanges up to 2″	2 5 0	10/6

The New "SIMPLE" TELEPHOTO LENS (complete).

This is complete in itself, and is a wonderful little instrument, the positive can be used **alone,** and the two combined give foci from 6 in. to 36 in., or more according to the camera extension available.

The "Simple" Telephoto Lens complete (consisting of positive f/7·7 in Bausch & Lomb shutter, iris diaphragm, and 2½ in. negative element in brass. Supplied in case complete - - - - £3 3 0.

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

BECK LENSES.

SETS OF LENSES

suitable for a half-plate camera from the most complete series to a simple lens.

½-plate Complete Set—1 No. IV. Set of Convertible Orthostigmats, with foci 10 in., 12½ in., 14½ in., 6½ in., 7⅛ in., 7¾ in.,	£12 12 6
½-plate Set—1 No. Va. Convertible Orthostigmats, 3 foci, 7¾ in., 12½ in., 14½ in.	£8 10 0
½-plate Set—1 No. V. Series 1. Orthostigmat, 2 foci, 12½ in., 7⅛ in.	£7 5 0
½-plate Lens—1 No. V. Biplanat, f/5·8	£3 10 0
½-plate Lens—1 No. IV. Double Aplanat, f/7·7	£2 0 0

A Telephoto Attachment may be supplied to all the above, ¼-plate and 5 × 4 Sets, at corresponding prices.

SETS OF CAMERAS AND LENSES.

SET No. I. For all work or any kind. Best quality square model Double Extension Camera, with 3 double dark slides, special tripod and head for tilting, Beck-Steinheil lens, telephoto attachment, standard and low power interchangeable, with 2 scales fully engraved, mounted in magnalium, with special focal plane shutter, giving exposures from ⅛ to $\frac{1}{800}$, complete in leather case with iris shutter, mounted on the lens, exposures 3 secs. to $\frac{1}{150}$.

¼-plate Outfit complete	£29 6 0
½-plate Outfit complete	34 8 6

SET No. II. Best quality Sanderson Model Camera, with all adjustments, and Beck-Steinheil lens and standard power telephoto attachment, with iris shutter on the positive in brass, with tripod and 3 double dark slides, in canvas case complete, exposures from 1 sec. to $\frac{1}{100}$.

¼-plate Outfit complete	£17 17 0
5 × 4 Outfit complete	19 9 6
½-plate Outfit complete	23 4 6

SET No. III. Best quality Sanderson Model Camera, with all adjustments and Beck double aplanat lens, f/7·7, and standard power telephoto attachment with roller-blind shutter, tripod and double darks, in soft canvas case complete.

¼-plate Outfit complete	£11 16 6
5 × 4 Outfit complete	13 2 6
½-plate Outfit complete	15 5 6

Full Catalogues and Detailed Particulars on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

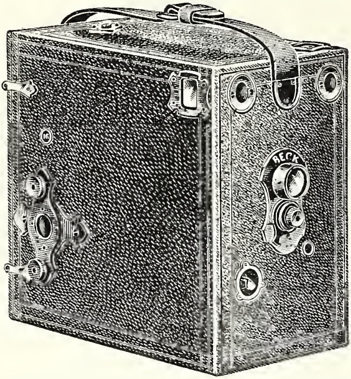
HAND CAMERAS FITTED WITH "BECK" LENSES.

THE FRENA.

This type of camera takes photographs upon stiff celluloid films about the stiffness of a postcard. They are placed in a packet, of any number up to 40, into the camera, and are dealt out one by one as used—"Like a Pack of Cards." The two most recent models, the "FRENA MAX" and the "F.O.P. FRENA," take also glass plates in sheaths. Glass plates can also be used in all the other models.

One of the chief causes of the popularity of the Frena Cameras has been the quality of the lenses with which they are provided.

They all carry brilliant "stationary" finders, an adjustable shutter, diaphragms to the lens, and all necessary adjustments.



THE FRENA MAX.

40 5 in. × 4 in. Films

or

12 ¼-plates in sheaths.

The films or plates are carried in a magazine which swings on centres in the sides of the case. A single motion of the handle at the side turns down the magazine and automatically drops one film or plate into the bottom of the camera, leaving the next ready for exposure; an automatic counter shows the number used. The shutter gives exposures of $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{80}$ second, and time exposures. The lens is provided with diaphragms. A handbook of 60 pages is supplied with each camera, giving instructions sufficiently complete to enable the beginner to successfully learn photography. The camera measures 8½ in. × 9½ × 4¼ in.

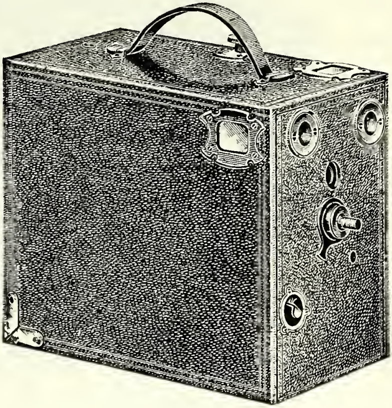
PRICE with Double Meniscus Lens -	£2	18	6
With Beck Autograph R.R. Lens -	5	5	0
With Beck-Steinheil Orthostigmat -	**9**	**9**	**0**

Fuller Particulars and Illustrated Lists Post-free on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

Hand Cameras Fitted with "Beck" Lenses.

THE FRENA.



The F.O.P. Frena takes 40 flat films, $3\frac{1}{2}$ in. × $2\frac{5}{8}$ in., or 10 glass plates in sheaths. It measures $6\frac{7}{8}$ in. × $6\frac{1}{4}$ in. × 4 in. It has a shutter, giving exposures $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{80}$ second, and time exposures. A complete Handbook of Instructions is supplied with each.

Price with Single Achromatic Lens - - - - -	£1	1	0
Price with Rapid Rectilinear Lens and Iris Diaphragm - - - - - - - - - - - - - -	3	17	6
Price with Beck-Steinheil Orthostigmat Lens and Iris Diaphragm - - - - - - - - - -	**6**	**7**	**6**

Fuller Particulars and Illustrated Lists Post-free on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

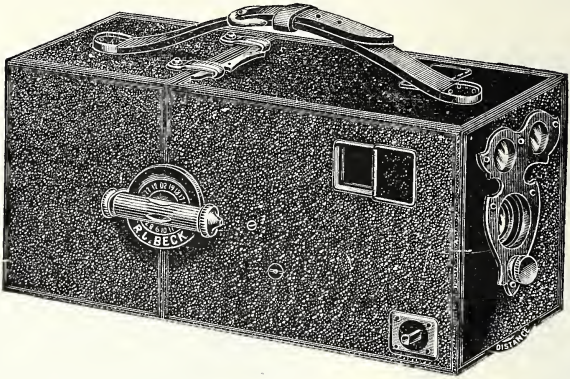
Hand Cameras Fitted with Beck Lenses.

THE FRENA

STANDARD BOX MODEL TYPE.

8 Sizes.

½ × 2½
—
4¼ × 3¼



4¼ × 3¼
—
5 × 4

THE BOX MODEL FRENAS.

These Cameras have established a reputation which is justly envied, and have done so largely through their reliability. A short description is given on the following pages, but our full-illustrated catalogue will be posted with sample prints on receipt of a post card.

They all take Forty Flat Films like a Pack of Cards which are dealt out one by one—they always remain Flat.

No.	Lens.	Size.	Apertures.	Shutter Speeds.	Weight	Size.	Price.
00	Single Achro.	3½ × 2⅝	f/11 16 22 64	1/5 1/10 1/20 1/40 1/80	2¾	9½ × 5 × 3½	£2 18 8*
0	R.R.	3½ × 2⅝	f/8 11 16 22 64	1/5 1/10 1/20 1/40 1/80	2¾	9½ × 5 × 3½	5 5 0*
0	**B.S.O.**	**3½ × 2⅝**	**f/6·3 11 16 22 64**	1/5 1/10 1/20 1/40 1/80	**2¾**	**9½ × 5 × 3½**	**8 15 0***
22	S.A.L.	4¼ × 3¼	f/11 16 22 64	1/5 1/10 1/20 1/40 1/80	4	11½ × 5½ × 4½	5 8 6*
2	R.R.	4¼ × 3¼	f/8 11 16 22 64	1/5 1/10 1/20 1/40 1/80	4	11½ × 5½ × 4½	8 17 6*†
2	**B.S.O.**	**4¼ × 3¼**	**f/6·8 11 16 22 64**	1/5 1/10 1/20 1/40 1/80	**4**	**11½ × 5½ × 4½**	**13 12 6*†**
3	R.R.	5 × 4	f/8 11 16 22 64	1/5 1/10 1/20 1/40 1/80	5½	12½ × 6½ × 5½	12 12 0*†
3	**B.S.O.**	**5 × 4**	**f/6·3 11 16 22 64**	1/5 1/10 1/20 1/40 1/80	**5½**	**12½ × 6½ × 5½**	**18 2 0*†**

* Complete with 40 Flat Films and a Handbook of Instructions. † Including 4 Magnifiers.

SOLID. RELIABLE. ELEGANT. SERVICEABLE. ENGLISH.

Fuller Particulars and Illustrated Lists Post-free on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

Description of the Box Model Frena Cameras.

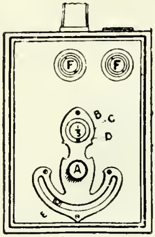


Fig. 8.—Front View.

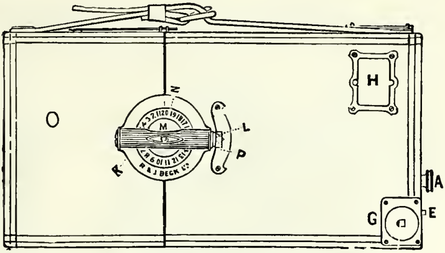


Fig. 9.—Side View.

A—Shutter Knob.
B—Exposure Number.
C—Diaphragm Plate.
D—Stop Number.
E—Stop Handle.
F—Finder Lenses.
G—Shutter Set Off.
H—Finder Aperture.
K—Handle.
L—Register Spring.
M—Level.
N—Indicator.
O—Receiver.
P—Register Plate.

The Frena Shutter gives instantaneous exposures, $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{80}$ of a second, the addition of the slow $\frac{1}{5}$ of a second will be found a great boon, time exposures of any duration may also be given. The perfect ratio of the different exposure is carried out in this shutter, $\frac{1}{5}$ is *always* twice as long as $\frac{1}{10}$, etc.

The shutter is manipulated as follows:—

Wind the Shutter.

This is done by turning the central milled knob which projects from the front of the case, just below the lens aperture (A, Fig. 8.) If the knob will not turn the shutter is already wound. When the shutter is completely wound the exposure number (B, Fig. 8) should be seen through the small aperture in the Camera front; this indicates the speed of the shutter in fractions of a second.

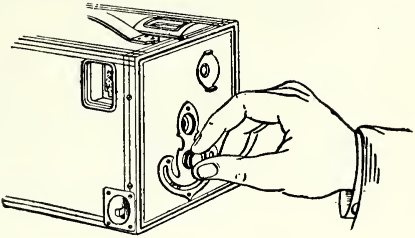


Fig. 10.

Setting Off the Shutter.

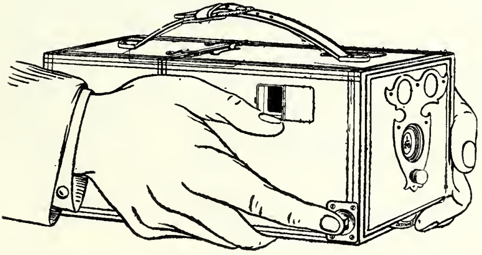


Fig. 11.

To set off the Shutter press in the bolt at the right-hand forward end of the side of the Camera, it should be pressed gradually right home.

Time exposures are obtained by first seeing that the shutter is set to $\frac{1}{5}$ of a second, then instead of pressing in the set off bolt, by pulling it out, which opens the lens, and after the exposure is complete, by pushing it in, which closes the lens.

Description of the Box Model Frena Cameras.

The Changing Mechanism of the Box Model Frena Cameras.

As has been pointed out the essential idea of the Frena system is to deal with 40 flat films "like a pack of cards." The object is the same in all types, but the method is slightly different.

Ready to Change the Film.

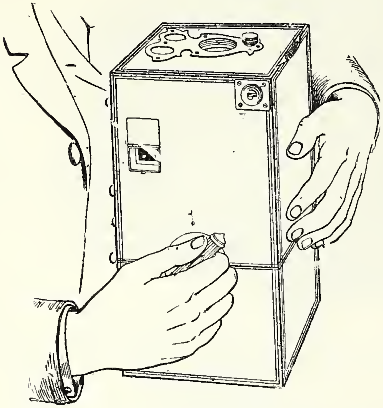


Fig. 12.

To Change the Films hold the lens end pointing upwards.

Grasp the level handle by the ends; and the handle can be revolved. It will be found that it will move in one direction for a short distance only, while in the other it will revolve a complete half turn.

To change the film, the handle must be rotated a half revolution, allowed to remain for a second or two and then returned to its original position, when it locks into the register plate so as to be ready for the next exposure.

This motion has turned the chamber round holding the films to face the bottom end of the Camera, at the same time slipping the pins along so that one film and its backing card has dropped into the receiving end of the Camera, leaving the next of the 40 films ready to receive the picture on being turned back.

There is an indicator fitted to this Camera to count the exposures.

The Changing Mechanism of the Box Model Frena No. 00.

The holder is detachable from the Camera and can be filled with forty flat films like a pack of cards as indicated in (Fig. 14).

It is this rotary form of changing which allows of the swing back being utilized, for as can be readily seen, if the Camera is pointed upwards by slightly rotating this holder, the photographic film can be placed in a plumb or vertical position, a spirit level on the handle indicating when this is the case.

The Frena Finders

are large sized "Cornex" as mentioned before, indeed these finders are fitted to all Frena Cameras, greatly enhancing their utility.

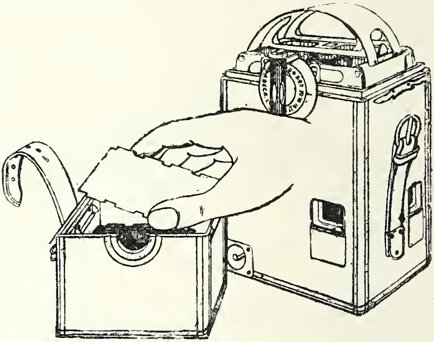
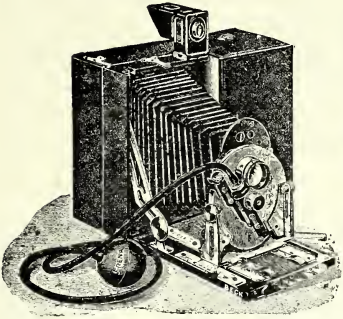


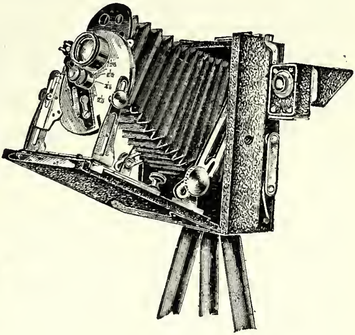
Fig. 14.

HAND CAMERAS FITTED WITH "BECK" LENSES.

THE FOLDING FRENAS.



No. 8 Frena.



8G.

TAKES 40 FLAT FILMS LIKE A PACK OF CARDS.

These Cameras are the outcome of the "Frena System" of film changing, and possess all the adjustments of the most complicated cameras. They take up very little room, all the adjustments of front and shutter occupy a space of 1⅝ deep. The shutter gives a faithful range of speeds from $\frac{1}{10}$ second to $\frac{1}{120}$. Full descriptive list on application.

No.	Lens.	Size.	Apertures.	Shutter Speeds.	Size.	PRICE.
8	**B.S.O.**	**4¼×3¼**	**f/6·3 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**8¼×5⅝×3¼**	**£11 18 6†**
8G	**B.S.O.**	**4¼×3¼**	**f/6·3 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**5⅜×4¼×1⅝**	**10 7 0**
***8GG**	**B.S.O.**	**4¼×3¼**	**f/6·3 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**8¼×5⅝×3¼**	**14 7 6**
8A	**B.S.O.**	**4¼×3¼**	**f/6·8 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**5⅝×4¼×1⅝**	**12 16 0†**
8AG	**B.S.O.**	**4¼×3¼**	**f/6·8 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**8¼×5⅝×3¼**	**11 4 6**
***8AGG**	**B.S.O.**	**4¼×3¼**	**f/6·8 8 11 16 22**	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	**8½×5⅝×3¼**	**15 4 6**
7	R.R.	4¼×3¼	f/8 11 16 22 32	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	8¼×5⅝×3¼	9 8 6†
7G	R.R.	4¼×3¼	f/8 11 16 22 32	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	8¼×5⅝×3¼	7 17 0
6	S.V.A.	4¼×3¼	f/11 16 22 64	$\frac{1}{10}$ $\frac{1}{20}$ $\frac{1}{40}$ $\frac{1}{80}$ $\frac{1}{120}$	8¼×5⅝×3¼	5 8 6†

* For Telephoto Work.

† Complete with 40 Flat Films and a Handbook.

Fuller Particulars and Illustrated Lists Post-free on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

The Frena System of Magnifiers

For portraiture and copying, The fixed focus Frena Cameras Nos. 00, 0, 22, 2, 3, 6, 10, 11, 12, will give sharp pictures of all objects from the horizon to a certain definite distance from the Camera. In the No. 10 for instance, everything beyond 15 ft. will be sharp, but objects nearer to the Camera than this distance will be out of focus. By the use of Frena Magnifiers, near objects can be photographed. This system was first introduced by ourselves, and was so successful a means of focussing in a fixed focus camera that it has been very widely imitated, but it must be remembered that as these additional lenses are to combine with the ordinary Camera lens they must be carefully computed to give good results, and the quality of the Frena Magnifiers goes a long way to make this system successful.

No Frena is complete without the ordinary Set of Magnifiers, and those of higher power greatly increase the scope of the instrument.

THEIR USE.

It is important that the distance of the object from the front of the Camera should be accurately estimated. With the High-power Magnifiers this is especially important, as the depth of focus is limited, and it is also advisable with these to stop the Lens down somewhat if microscopic definition at the corners of the plate is desired.

It will be found that when the object is very near to the Camera, say within 2 feet, the Finders will not be quite accurate for ascertaining the position of the image on the Film, and it will be necessary to arrange the Camera so that the Lens is pointing exactly towards the centre of the object. This may be done if both Object and Camera rest upon the same table, by measurement, rising the Camera up until the centre of the Lens is at the same distance from the table as the centre of the object, or it may be done by looking along the centre of the Camera side and the centre of the Camera top.

List of Magnifiers, giving the Distances from the Front of the Cameras at which objects are in focus at f/II.

These Distances can be somewhat increased by using a small Stop, which is always recommended for any Magnifier higher than No. 4.

Magnifier.	Distances at which the Magnifiers are to be Used.																								
	Frena No. 00 and 10.					Frena No. 0, 11 & 12.					Frena No. 22.					Frena No. 2. 13 × 14.					Frena No. 3.				
	ft.	in.		ft.	in.	ft.	in.		ft.	in.	ft.	in.		ft.	in.	ft.	in.		ft.	in.	ft.	in.		ft.	in.
1	10	0	to	6	0	10	0	to	6	0	29	0	to	7	0	32	0	to	9	0	30	0	to	12	0
2	6	0	to	4	0	6	0	to	4	0	10	0	to	6	0	10	0	to	6	0	12	0	to	7	0
3	4	0	to	2	6	4	0	to	2	6	6	0	to	4	6	6	0	to	4	6	6	6	to	5	0
4	2	1	to	1	8	2	4	to	1	11½	4	6	to	3	6	4	6	to	3	6	4	0	to	3	6
5	1	5½	to	1	2½	1	10	to	1	5½	2	3	to	1	10	2	6	to	2	1	2	5	to	2	2½
6	1	1½	to		11½	1	2½	to	1	0½	1	9	to	1	6	1	11	to	1	8½	1	10½	to	1	8½
7		10½ inches					9¾ inches				1	5	to	1	3	1	6½	to	1	4½	1	6	to	1	4½
8		8¾	do.				8	do.			1	1	to	1	0	1	2	to	1	1	1	2½	to	1	1½
9		7	do.				7	do.				9¾ inches					9½ inches					9¾ inches			
10		..		..			..		..			8	do.				8½	do.				8¼	do.		
11		..		..			..		..			7	do.				7½	do.				7	do.		

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

FRENA MAGNIFIERS—Continued.

Approximate Distance of the Object from the Front of the Camera to produce the following sizes :—

Size of Picture.	Frena Nos. 00 & 10.		Frena Nos. 0, 11 & 12.		Frena Nos. 22 & 6.		Frena No. 2. 13 × 14		Frena No. 3.	
	Distance	Magnifier to be used.	Distance.	Magnifier to be used	Distance.	Magnifier to be used.	Distance.	Magnifie. to be used.	Distance.	Magnifier to be used
	ft. in.	No.	ft. in.	No.	ft. in.	No.	ft. in.	No.	ft. in.	No.
$\frac{1}{20}$ Full size	7 8	1	7 8	1	9 1	1	9 0	2	10 8	2
$\frac{1}{15}$ do.	5 6	2	5 6	2	7 1	2	6 6	2	8 0	2
$\frac{1}{10}$ do.	3 9	3	3 9	3	4 7	3	4 8	3	5 6	3
$\frac{1}{8}$ do.	3 0	3	3 0	3	3 8	4	3 8	4	4 0	4
$\frac{1}{5}$ do.	2 0	4	2 0	4	2 3	5	2 3	5	..	..
$\frac{1}{4}$ do.	1 6	5	1 6	5	1 10	5	1 10	6	2 3	5
$\frac{1}{3}$ do.	1 2	6	1 2	6	1 4	7	1 6	7	1 9	6
$\frac{1}{2}$ do.	9	8	9½	7	1 0	8	1 0	8	1 2	8
$\frac{2}{3}$ do.	7	9	7½	9	8½	10	8½	10	8	10
$\frac{4}{5}$ do.	..	..	..	.	7	11	7½	11	..	..
Full size	..	..	..	..	..	..	..	..	7	11

The above Table is of use to those who are anxious to use these Cameras for many interesting branches of work usually barred to the box model camera worker. Flowers, curios and various other kindred subjects, such as copying pictures, engravings, etc., can, as a matter of fact, be more rapidly carried out by this method than by any other means of focussing. The accuracy and finish of Frena Magnifiers is guaranteed by the fact that both lenses and the magnifiers are made at our own factory. A further advantage of this method of focussing is the fact that the apertures retain their relative value. f/.. is always f/... This is useful when using an exposure meter.

In the bellows form cameras the value of the aperture varies for every object at different distances from the Camera.

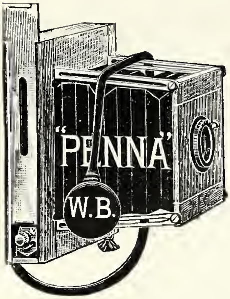
PRICES OF THE FRENA MAGNIFIERS.

No. of the Magnifier.	Frena Nos. 00 & 10.		Frena Nos. 0. OBS 11 & 12.		Frena Nos. 22 & 6.		Frena Nos. 2 & 2BS. 13 × 14.		Frena No. 3 and No. 3 BS.	
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
1	2 6	7 6 In case.	2 6	7 6 In case.	2 6	10 6 In case.	2 6	10 6 In case.	2 6	10 6 In case.
2	2 6		2 6		2 6		2 6		2 6	
3	2 6		2 6		2 6		2 6		2 6	
4	4 0	12 6 In case.	4 0	12 6 In case.	2 6		2 6		2 6	
5	4 0		4 0		4 0	15 0 In case.	4 0	15 0 In case.	4 0	15 0 In case.
6	4 0		4 0		4 0		4 0		4 0	
7	4 0		4 0		4 0		4 0		4 0	
8	4 0		4 0		4 0		4 0		4 0	
9	4 0		4 0		5 0		5 0		5 0	
10	..		..		5 0		5 0		5 0	
11	..		..		5 0		5 0		5 0	

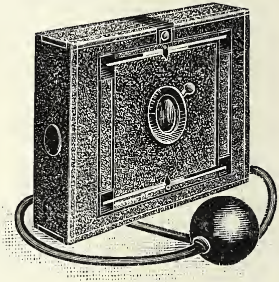
Hand Cameras Fitted with Beck Lenses.

THE "PENNA"

A FOCAL PLANE CAMERA.



The Camera extended showing the speed knob exposed.



The Camera closed for the pocket, showing the front flush with the rest of the Camera.

The Shutter gives speeds from $\frac{1}{8}$ to $\frac{1}{800}$ second. The alterations of speed are all made from outside, the Blind itself has not to be touched. It takes double dark slides or the Frena Film Holder, carrying 20 flat films. The Lens is supplied in a focussing mount with engraved scale of distances and Iris diaphragm. The Camera has cross and rising front and Cornex Finder. When folded the $\frac{1}{4}$-plate size is under 2 inches in thickness, and is very rigid when set up.

PRICES.

Beck-Steinheil Penna Folding Focal Plane Camera, for plates $4\frac{1}{4} \times 3\frac{1}{4}$, with **Cross** and **Rising Front,** and giving exposures of any duration or $\frac{1}{8}$ to $\frac{1}{800}$ of a second, with **Orthostigmat Lens No. 3, Series I., f/6·3, $4\frac{3}{4}$ Focus,** in special focussing mount with Iris, **Three Double Dark Slides,** aluminium mounted (Wallis Bros. Patent). Price, £10 0 0

Beck's Patent Frena Film Holder, takes 20 flat films like a pack of cards in place of the double dark slides with camera, as above £11 0 0

Beck-Steinheil Penna Folding Focal Plane Camera, for plates 5 × 4, with **Cross** and **Rising Front,** and giving exposures of any duration or $\frac{1}{8}$ to $\frac{1}{800}$ of a second, with **Orthostigmat Lens No. 4, Series I., f/6·3, $5\frac{15}{16}$ Focus,** in special focussing mount with Iris **Three Double Dark Slides,** aluminium mounted (Wallis Bros. Patent). Price, £11 10 0

Beck's Patent Frena Film Holder, takes 20 flat films like a pack of cards in place of the double dark slides with camera, as above *£12 15 0

Beck-Steinheil Penna Folding Focal Plane Camera, for plates $6\frac{1}{2} \times 4\frac{3}{4}$, with **Cross** and **Rising Front,** and giving exposures of any duration or $\frac{1}{8}$ to $\frac{1}{800}$ of a second, with **Orthostigmat Lens No. 5, Series I., f/6·3, $7\frac{1}{8}$ Focus,** in a special focussing mount with Iris, **Three Double Dark Slides,** aluminium mounted (Wallis Bros. Patent). Price, £13 10 0

Beck's Patent Frena Film Holder, takes 20 flat films like a pack of cards in place of the double dark slides with camera, as above *£14 12 6

*There is a slight charge for fitting if both dark slides and holder are required.

The Camera is supplied with Biplanat or Rapid Rectilinear Lenses at a corresponding reduction in price.

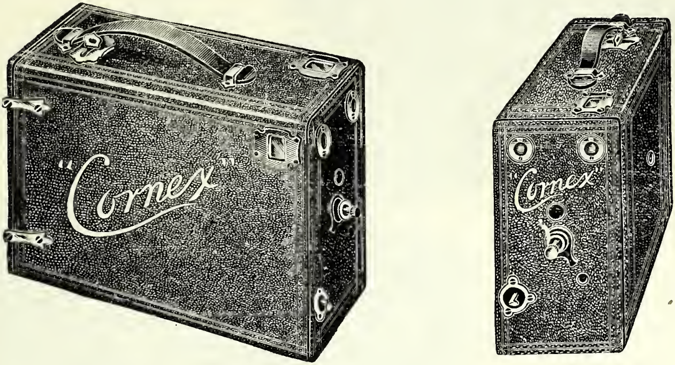
Fuller Catalogues on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

HAND CAMERAS FITTED WITH "BECK" LENSES.

THE "CORNEX"

(Magazine Plate Cameras).



MODELS A, B and C, ¼-plate.

The "Cornex" Camera takes 12 plates in sheaths, which fit into the back portion of the camera, pressed into position by a spring on the back door—by moving the sliding crown-shaped projection on the top of the camera once forward and back the foremost plate is dropped into the bottom portion of the camera. Any plate can be removed for development without disturbing the unexposed plates. The sheaths, with their plates, can be placed into the camera in any order, and the changing mechanism is simple and reliable. Two brilliant stationary finders are supplied—one for horizontal. and one for vertical positions. A tripod screw and two bushes are supplied with each camera. The shutter gives exposures $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{80}$ second, and time exposures. The lens is provided with diaphragms, and an automatic counter registers the number of plates exposed. The camera is strong, substantially made, and is well covered.

PRICES OF THE "CORNEX" CAMERAS, MODELS A, B AND C.

A	Single Achromatic Lens - -	£1 1 0
B	Beck Double Meniscus Lens	1 10 0
C	Beck Rapid Rectilinear Lens	2 2 0

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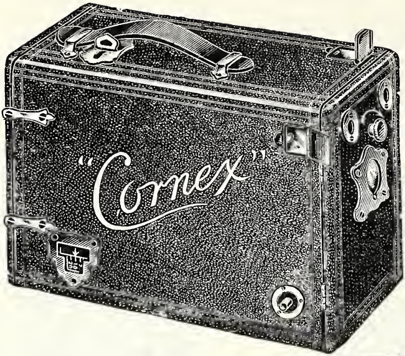
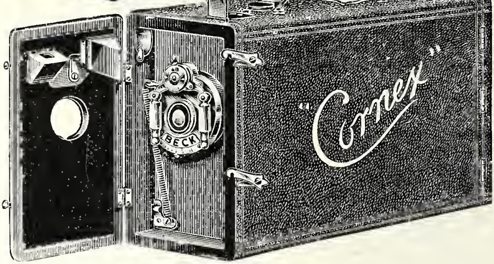
R. & J. BECK, Ltd., 68, Cornhill, London, E.C.



HAND CAMERAS FITTED WITH "BECK" LENSES.

THE "FOCUSSING CORNEX"

(Magazine Plate Cameras).



MODELS D, E, F and G

(Fitted with "Beck" Lenses).

These models have the same changing apparatus for 12 plates, but are provided with an accurate and delicate focussing adjustment. At the right-hand side is a travelling scale of feet and index to indicate the position of focus for objects at different distances from the camera. The front of the camera opens, exposing the lens and shutter to view. The lens has an iris diaphragm, and the shutter is of the well-known pneumatic type, giving exposures of 1, $\frac{1}{2}$, $\frac{1}{5}$, $\frac{1}{25}$, $\frac{1}{50}$, $\frac{1}{100}$ of a second, and time exposures either of long duration (one press of the set-off opening and the second closing the lens), or of short duration, the lens remaining open only during the pressure of the set-off. The finders are "brilliant stationary" with folding covers. The shutter is wound and set off from outside the camera, and the speeds are changed by opening the front.

THE "CORNEX" PLATE CAMERAS, D,* E,* F* and G.*

D	Rapid Rectilinear Lens - - - -	£3 3 0
E	Double Aplanat Lens - - - - -	4 4 0
F	Biplanat Lens - - - - - - - - -	5 0 0
G	**Beck-Steinheil Orthostigmat Lens -**	**8 8 0**

* Fitted with the "Cornex Patent Index" (see next page).

Fuller Particulars and Illustrated Lists Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

THE "CORNEX (PATENT) INDEX"

(as fitted to the "Cornex" Magazine Plate Cameras and to the "British Ensign.")

The "Cornex" Cameras Models D, E, F, G (Focussing Models), are focussed by means of a revolving handle, which is recessed into the bottom of the camera. Revolving this handle moves the whole inner case, which carries the plates to and fro. This is accomplished by a spiral groove on a revolving disc, into which fits a stud connected with the inner casing. By this means a very steady and delicate motion is obtained. On the right-hand side of the camera, at the lower back corner, is the scale which indicates the distance in feet to which the camera is set. Fig. A shows this scale, which is a patent scale upon a new principle; the lower portion, carrying a series of divisions which represent feet, moves as the focussing handle is turned, the upper portion remains stationary, and the arrow in the centre points to the distance that is most sharply focussed. In the figure it is shown set to 40 feet. On either side of this arrow are divisions marked with the apertures of the lens. These divisions represent the depth of focus of the lens, thus in fig. A, although 40 feet is the most exact focus, if the stop f/11 is used all objects between 20 feet and 50 feet will be sharp in the photograph, or if f/16 be used all objects between 7 feet and 100 feet will be sharp. In this way the new "Cornex" Index not only shows the correct focus, but also what is in focus on either side.

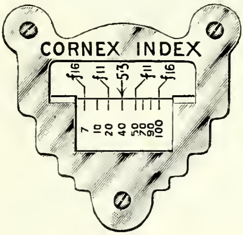


Fig. A.

The "Cornex Index," even to the uninitiated, is quite as easy to use as the ordinary scale if the following point is remembered: Always set the right-hand line of the upper scale (fig. A), representing the aperture in use, to the most distant object included in the picture, and the rest will look after itself.

This index is a patent, and is fitted in different forms—that are different in design, not in principle—to the cameras manufactured by ourselves; it makes careful focussing possible with lenses of large aperture.

PERFECT FOCUSSING WITH HIGH-CLASS LENSES.

Fuller Particulars and Catalogues Post-free from

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

HAND CAMERAS FITTED WITH BECK LENSES.

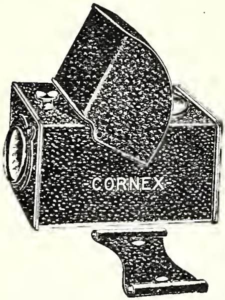
In addition to the Hand Cameras described, the following makes can be supplied fitted with Beck and Beck-Steinheil Lenses:—

The "Amber" Camera,
The "Anschutz" Camera,
The "Automan" Camera,
The "British Ensign" Camera,
The "Cameo" Camera,
The "Carbine" Camera,
The "Challenge" Camera,
The "Dayroll" Camera,
The "Ensign" Camera,
The "Ilex" Camera,
The "Midg" Camera,
The "Maxim" Camera,
The "N. & G." Cameras,
The "Nydia" Camera,
The "Panoramic" Cameras,
The "Pony Premo" Camera,
The "Primus" Camera,
The "Ruby" Camera,
The "Sanderson" Camera,
The "Victo" Cameras,
The "Weno" Camera,
The "Xit" Camera.

Any make of camera can be fitted to order.

THE CORNEX FINDER.

The Cornex Finder is a new type of Brilliant Finder, designed so as to overcome the disadvantages that have hitherto existed in most of the so-called Brilliant Finders.



The first object of a Finder is to correctly indicate the amount of view included on the photographic plate, and whilst the ordinary ground-glass form fulfils this purpose it has the great disadvantage of giving but a dim image.

To overcome this, the so-called Brilliant Finder was invented. This form gave a picture as vivid as the object itself, but it generally suffered from the serious defect that the amount of view included in the picture was not the same if the observer looked into it at different angles. In some cases the Finder was rendered quite unreliable by the extent to which this defect occurred—a slight movement of the observer's head making a very considerable difference in the amount of view included.

Price of Cornex Finder, for use with lenses of focus 5¼ in. or 5½ in. on ¼-plate, 6½ in. to 7 in. on 5×4, or 8 in. to 9 in. on ½-plate, 5/-. Finished bright, 7/6.

Fuller Particulars and Illustrated Lists Post-free on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

Optical Accessories for Photographic Lenses.

PRISMS FOR PROCESS WORK.

These are made in two qualities, but both qualities are sufficiently good for the most perfect work. The 1st Quality are larger compared with the size of the lens employed, and are in a somewhat more elaborate mount. The surfaces of those of both qualities are "figured" to a degree of great perfection, and will produce the very best work.

1st QUALITY.

Prices of Prisms for Process Orthostigmat Lenses, Series III.

For Orthostigmat.	PRICE.	For Orthostigmat.	PRICE.
No. 7. 11¾ in.	£15 0 0	No. 10. 23½ in.	£30 0 0
,, 8. 15¾ in.	20 0 0	,, 11. 29½ in.	37 10 0
,, 9. 19¾ in.	25 0 0	,, 12. 35½ in.	45 0 0

2nd QUALITY.

No.	Diameter of Lens.	PRICE.	No.	Diameter of Lens.	PRICE.
1	1 in. clear.	£3 0 0	10	2¼ in. clear.	£7 10 0
2	1¼ ,, ,,	3 15 0	11	2⅜ ,, ,,	8 5 0
3	1⅜ ,, ,,	4 2 6	12	2½ ,, ,,	9 0 0
4	1½ ,, ,,	4 10 0	13	2⅝ ,, ,,	9 15 0
5	1⅝ ,, ,,	4 17 6	14	2¾ ,, ,,	10 10 0
6	1¾ ,, ,,	5 5 0	15	2⅞ ,, ,,	11 5 0
7	1⅞ ,, ,,	5 12 6	16	3 ,, ,,	12 0 0
8	2 ,, ,,	6 0 0	17	3½ ,, ,,	18 0 0
9	2⅛ ,, ,,	6 15 0	18	4 ,, ,,	30 0 0

MIRRORS AND LIGHT FILTERS.

These Mirrors are silvered on the surface, and their surfaces, as well as those of the troughs or light filters, are all "figured" to the highest degree of accuracy. Second quality mirrors are supplied in which the surfaces are figured to a degree of accuracy sufficient for all process work. (Prices on application.)

Prices of Mirrors, Etc., for the Special (Series III.) Process Orthostigmats.

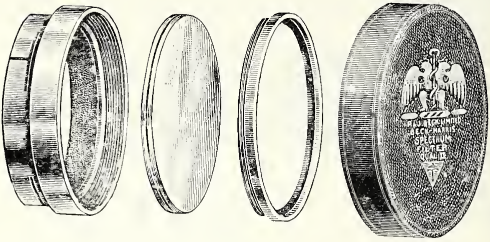
For Orthostigmats ..	No. 7	8	9	10	11	12
Focus	11¾	15¾	19¾	23½	29½	35½
Plane Mirror..	£15 0 0	£20 0 0	£24 0 0	£27 0 0	£30 0 0	£32 10 0
Light Filters	5 0 0	7 0 0	9 0 0	11 0 0	14 0 0	20 0 0

Prices of Second Quality Mirrors on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.

OPTICAL ACCESSORIES FOR PHOTOGRAPHIC LENSES.

BECK-HARRIS SPECTRUM FILTER.



Isochromatic Screens have been relegated to rather an unimportant position, owing to the fact that they have not always been manufactured as an optical accessory by lens makers, requiring as much attention as the lens itself. There are two points in which the Beck-Harris Screen shows a marked advance over other screens. It allows of the truest rendering of all colour values without increasing the necessary exposure in the same proportion.

There can only be one rendering of all colours in monochrome which reproduces their luminosities in the same proportion as seen by the eye. It is just as possible to over-correct for yellow and green as it is for the ordinary plates to under-correct.

With the Beck-Harris Filter the result is obtained with an increase of exposure of but 3 to 4 times according to plate used, and gives a greater differentiation than the ordinary yellow glass screen with 8 times the exposure.

Surprise may be experienced with regard to the relative prices of Quality I. and Quality II. The first is composed of two thick pieces of glass, so thick as to prevent any bend, and each of the 4 surfaces is figured with the same accuracy as the best of Process Prisms, and are specially designed for Process work, as they do not interfere in the slightest degree with the optical qualities of the finest of modern Anastigmats. If one of these screens were placed on a delicate long-focus lens of an aperture of f/6, the definition would be as critical as before, whereas if Quality II. were used, the definition would suffer slightly.

At the same time Quality II. is an advance over the ordinary Isochromatic Screen. Its 4 surfaces are such that they do not interfere with the definition for all ordinary work, landscape or architectural, and it is only at full aperture on fine lines that the difference between the two can be seen.

PRICES AND SIZES.

QUALITY I.
Figured Surfaces.

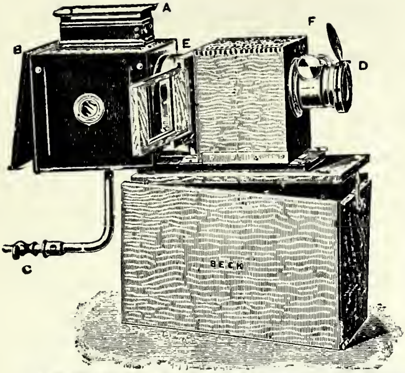
No.	Size.	For Orthostigmat No.	PRICE.
1	1"	1, 0, 0a	£1 10 0
2	1¼"		1 15 0
3	1½"	2, 3, 4, 2a, 3a	2 0 0
4	1¾"	5, 3b, 4a, 2b, 3b	2 15 0
5	2"	6, 7, 8, 8a	3 10 0
6	2¼"		4 0 0
7	2½"	9	5 0 0
8	2¾"		6 0 0
9	3"	10	7 0 0

QUALITY II.
Good Quality Parallel Surfaces.

No.	Size.	For Orthostigmat No.	PRICE.
1	1"	1, 0, 0a	£0 7 0
2	1¼"		0 7 6
3	1½"	2, 3, 4, 2a, 3a, 2b	0 7 6
4	1¾"	5, 4a, 3b	0 8 6
5	2"	6, 7, 8, 5a, 6b	0 9 6
6	2¼"		0 10 6
7	2½"	9	0 12 6
8	2¾"		0 12 6
9	3"	10	0 15 0

Full Catalogues on application to

R. & J. BECK, Ltd., 68, Cornhill, London, E.C.



THE "LUVEX" LANTERN.

This Lantern and set of apparatus has been specially designed for home use for displaying pictures to one's friends with the minimum of trouble.

The Lantern illustrated is arranged for ordinary gas, with the Welsbach Incandescent Burner. It has merely to be connected to the ordinary gas-burner by an indiarubber tube, and it is ready for immediate use. The whole lantern packs away into its box when not in use.

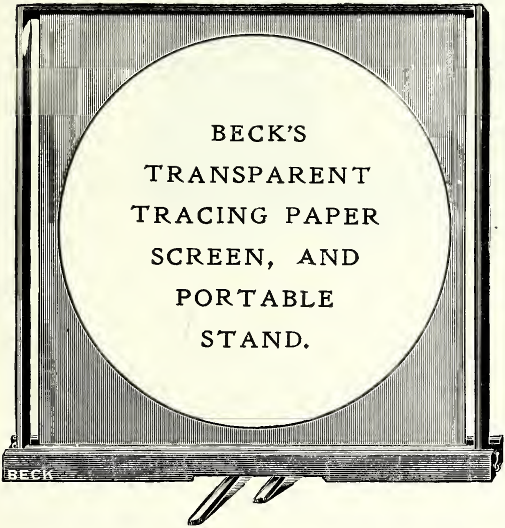
When house gas or electricity is not available, special estimates for limelight will be given.

Lantern, complete with Lens, Burner, Mantle, Condenser, Slide Carrier, and all Adjustments, complete in box,
£3 18 6.

Do., do., with 100 C.P. Focus Electric Light in place of Welsbach Burner,
£4 18 6.

3 ft. 6 in. Transparent Screen on Spring Roller Attachment, which can be erected in a few moments, or as rapidly packed away in its box,
10/6.

4 ft. Opaque Screen, in similar box and mounting,
12/6.



BECK'S TRANSPARENT TRACING PAPER SCREEN, AND PORTABLE STAND.

Complete Set of Apparatus for Making Lantern Slides,

Price 18/0.

Consisting of—
1 Printing Frame
3 Boxes of Lantern Plates
1 Box of Lantern Slide Binders
1 Box of Lantern Masks
3 Dozen Cover Glasses
1 Box of Spots for Lantern Slides
1 $3\frac{1}{4} \times 3\frac{1}{4}$ Developing Dish
1 $6\frac{1}{2} \times 4\frac{3}{4}$ Fixing Dish
1 Washing Rack and Tank
1 Drying Rack
2 Bottles of Hydrokinone Developer
1 Box of Hypo
1 2-oz. Measure Glass

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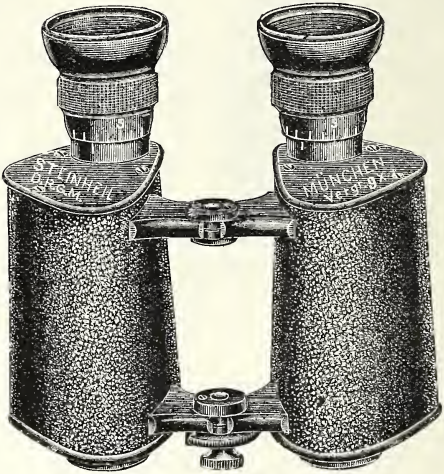
BECK'S PRISMATIC FIELD AND MARINE GLASSES.



The

"Steinheil" Prismatic Field Glasses.

In introducing to the English Market this Prismatic Double Telescope, Messrs. R. & J. Beck, Ltd., would particularly draw attention to the quality of the optical portions of these instruments. They believe that the superiority of these glasses is so marked as to specially appeal to those who are not content with an article of ordinary quality, however excellent the design.

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STEINHEIL PRISMATIC FIELD AND MARINE GLASSES.

These Field Glasses are composed of two telescopes, which, by the ordinary construction, would be nearly a foot in length, but by the use of the so-called "Porro" prisms, are reduced to the length of an ordinary field glass, retaining all the advantages of telescopes in the space of a field glass. There are four prisms, with twelve surfaces, which require to be of the very highest optical finish to ensure perfect results. The function of these prisms is simply to bend the rays collected by the object glasses on their way to the eyepieces, and in so doing to invert the image.

Messrs. Steinheil have been long connected with the manufacture of the finest telescopes, and their knowledge has enabled them to produce a lens system to work in combination with these prisms, which leaves nothing to be desired.

The object glass is of larger aperture than is usual in this class of Field Glass, the field being proportionately brighter. The eyepieces are also specially designed to give the best results in conjunction with the object glasses.

These glasses should be carefully adjusted to suit the distance between the eyes. This is done by bending the two halves till the margins of the fields appear to exactly coincide, showing only one circular aperture. Correct adjustment of this distance is of some importance.

The eyepieces should be focussed separately, to accommodate for any difference in the vision of the observer's eyes. The focussing is accomplished by rotating either eyepiece. If focussed for objects at 100 yards distance, all objects beyond will be sharp, and those much nearer, within certain limits, will also be sufficiently sharp. This is approximately the best distance to focus for.

PRICE, including Sling Strap and Case.

		Binocular.	Monocular
Model A	Magnifying 6 times, Angle of View, 6·7°	£7 0 0	£3 0 0
Model B	Magnifying 9 times, Angle of View, 4·4°	8 0 0	3 10 0
Model C	Magnifying 12 times, Angle of View, 3·3°	9 10 0	4 0 0
Model D	Magnifying 5½ times, Angle of View, 7·3°	12 0 0	5 0 0

Model D is specially made to give brilliant illumination for night work and foggy weather.

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MICROSCOPES from £3 3s. to £150.

The "Star" - - - - -	£3	3	0	to	£8	0	0
The "British Students'" -	5	0	0	to	15	0	0
The "London" - - - - -	5	0	0	to	35	0	0
The "Pathological" - -	10	0	0	to	50	0	0
The "Imperial" - - - - -	15	10	0	to	50	0	0

COMPLETE OUTFITS FOR LABORATORIES.

Microscope Catalogue Free.

TELESCOPES, FIELD GLASSES AND BINOCULARS

TO SUIT ALL REQUIREMENTS.

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supplied to Oculists' Prescriptions.

Sight is Tested Free, but spectacles are only prescribed for simple refraction defects, all difficult cases being referred to oculists.

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